FCC-SEED
Vertex detector project

Jeremy Andrea, Auguste Besson,
IPHC, CNRS, Unistra
On behalf of the FCC-SEED project

FCC-SEED
VERTEX DETECTOR
FOR FCC-ee

Introduction

- How it started : France has a long standing expertise in “Monolithic Active Pixel Sensor” (MAPS),
  - One of the main activity of development is the vertexing for e^+e^- collider @ILC,
  - But many more applications (examples in HEP: STAR, Alice, Belle-2, CBM),
  - This expertise can benefit a lot the FCCee project.

- In preparation of the European Strategy for Particle Physics Update, an expression of interests for a future Vertex Detector for FCCee , based on MAPS, has been prepared and signed by six in2p3 institutes.

- This triggered the creation of the FCC-SEED project, that will be presented during this seminar :
  - Short presentation of FCCee and detector concepts,
  - Specifications of a vertex detector, and advantages of the MAPS technology,
  - Preliminary performance studies based on full simulation,
  - Current tests for curved sensors.

- **This is only the start, and there a long road ahead.**

ESPPU timeline

End September 2024
Council appointment of the members of the **PPG** and decision on the venue for the **Open Symposium**

18 Dec 2024
GTS

December 2024
Council decision on the venue for the **ESG Strategy Drafting Session**

20-21 Jan 2025
French symposium

31 March 2025
Deadline for the submission of main input from the community

26 May 2025
Deadline for the submission of additional national input in advance of the **Open Symposium**

YOU ARE HERE

23-27 June 2025
Open Symposium

End September 2025
Submission of the "Briefing Book" to the **ESG**

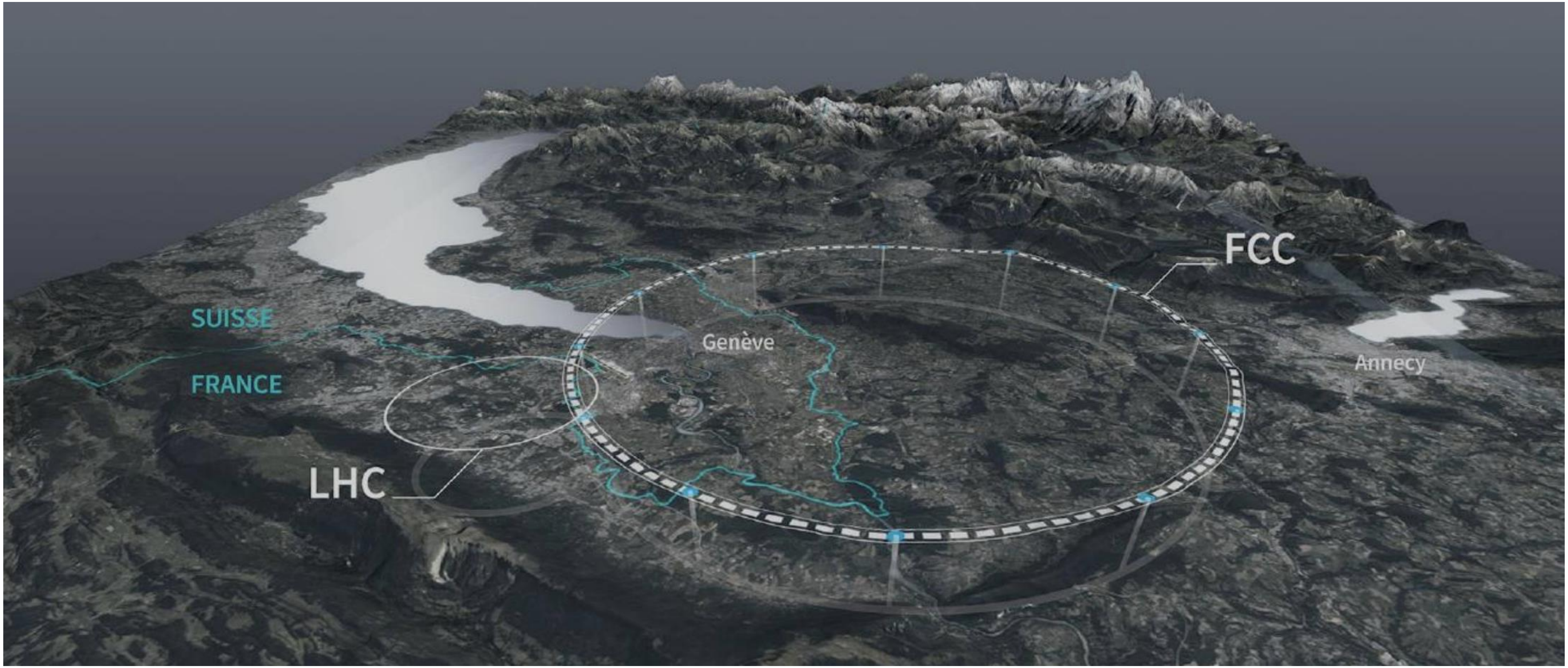
14 November 2025
Deadline for the submission of final national input in advance of the **ESG Strategy Drafting Session**

1-5 December 2025
ESG Strategy Drafting Session

End January 2026
Submission of the draft strategy document to the Council

March and June 2026
Discussion of the draft strategy document by the Council and **updating of the Strategy**

FCCee project



FCCee project

JEAN-PAUL BURNET, link

Tunnel Circumference: 90.7 km

Excavated vol: 6.2M m^3 (In the ground)

Access shafts: 12

Construction shafts: 1

Large experiment sites: 2

Small experiment sites: 2

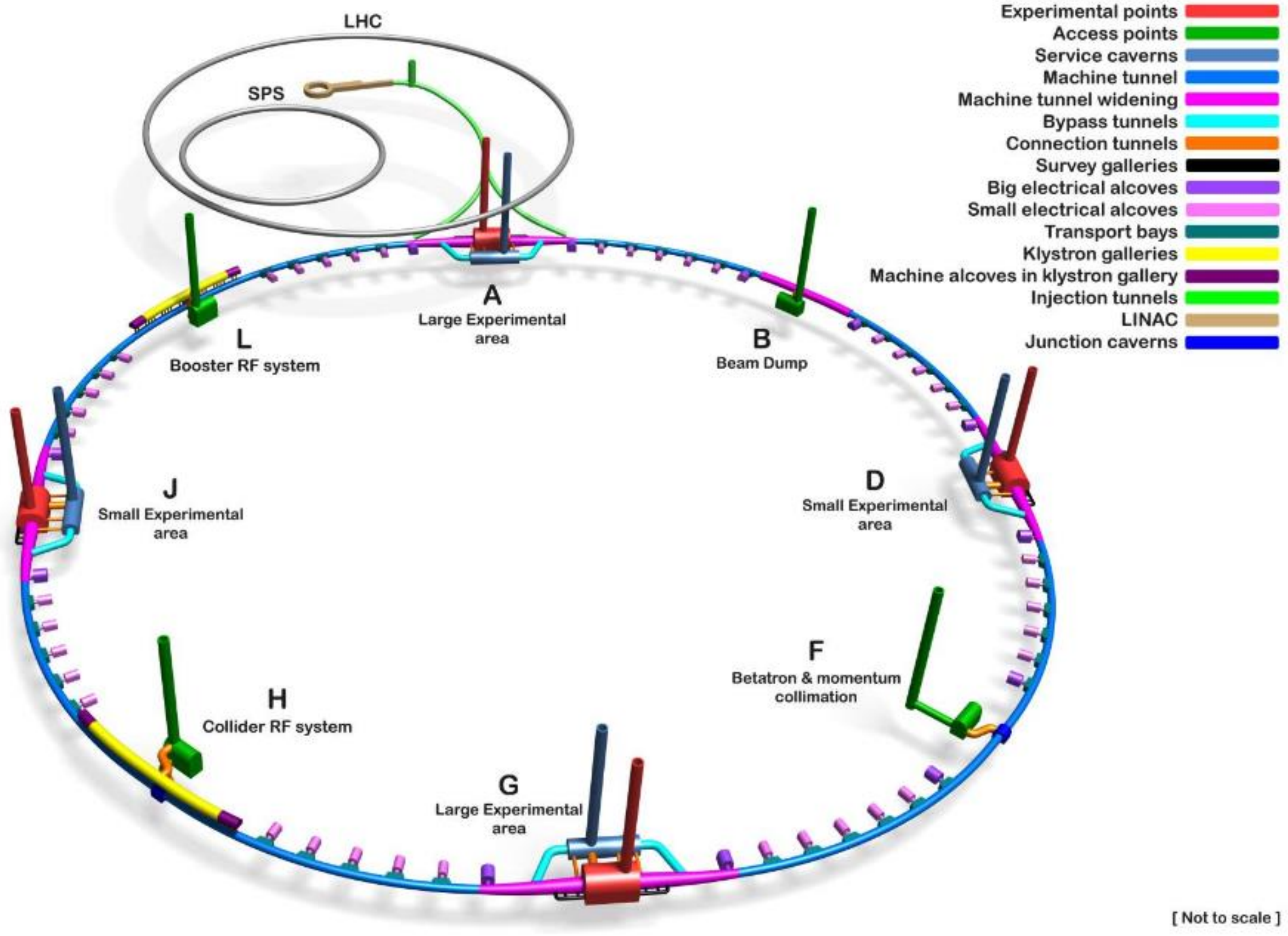
Technical sites: 4

Deepest shaft: 400m

Average shaft depth: 243m

Total concrete volume: 1.9 M m^3

Steel weight: 130,000 metric tonnes

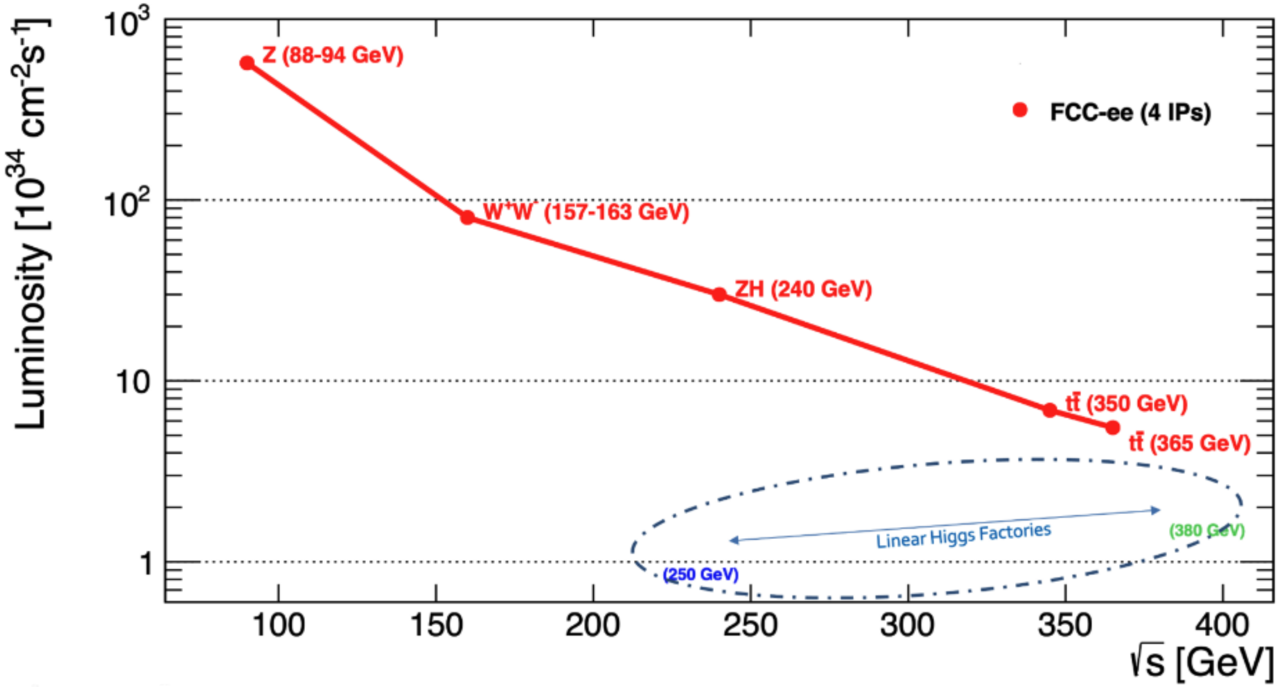


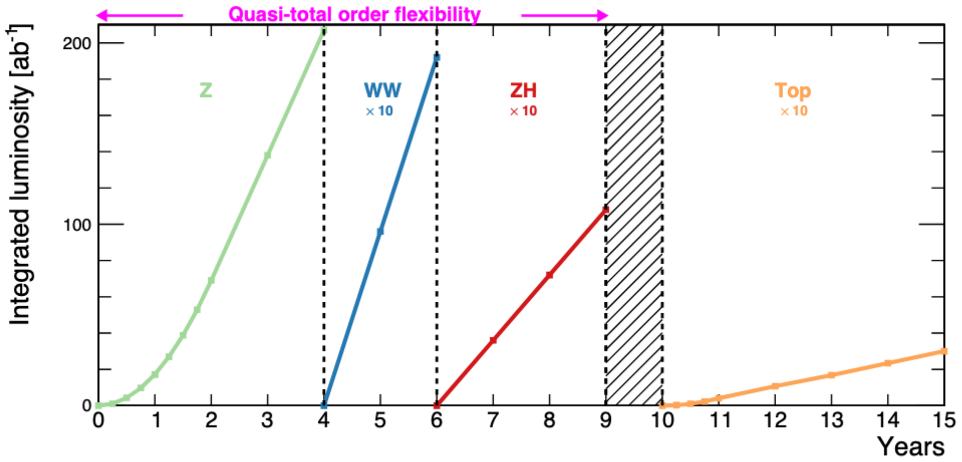
FCCee project

- e^+e^-colliders are know to be :
  - Higgs factories,
  - But also high precision machines.

- FCCee offers:
  - the largest coverage in terms of physics program,
  - the best sensitivity in almost all domains up to the $t\bar{t}$ mass threshold, thanks to its very high luminosity,
  - Has no polarisation and is limited to the $t\bar{t}$ mass threshold, until switched to FCChh.

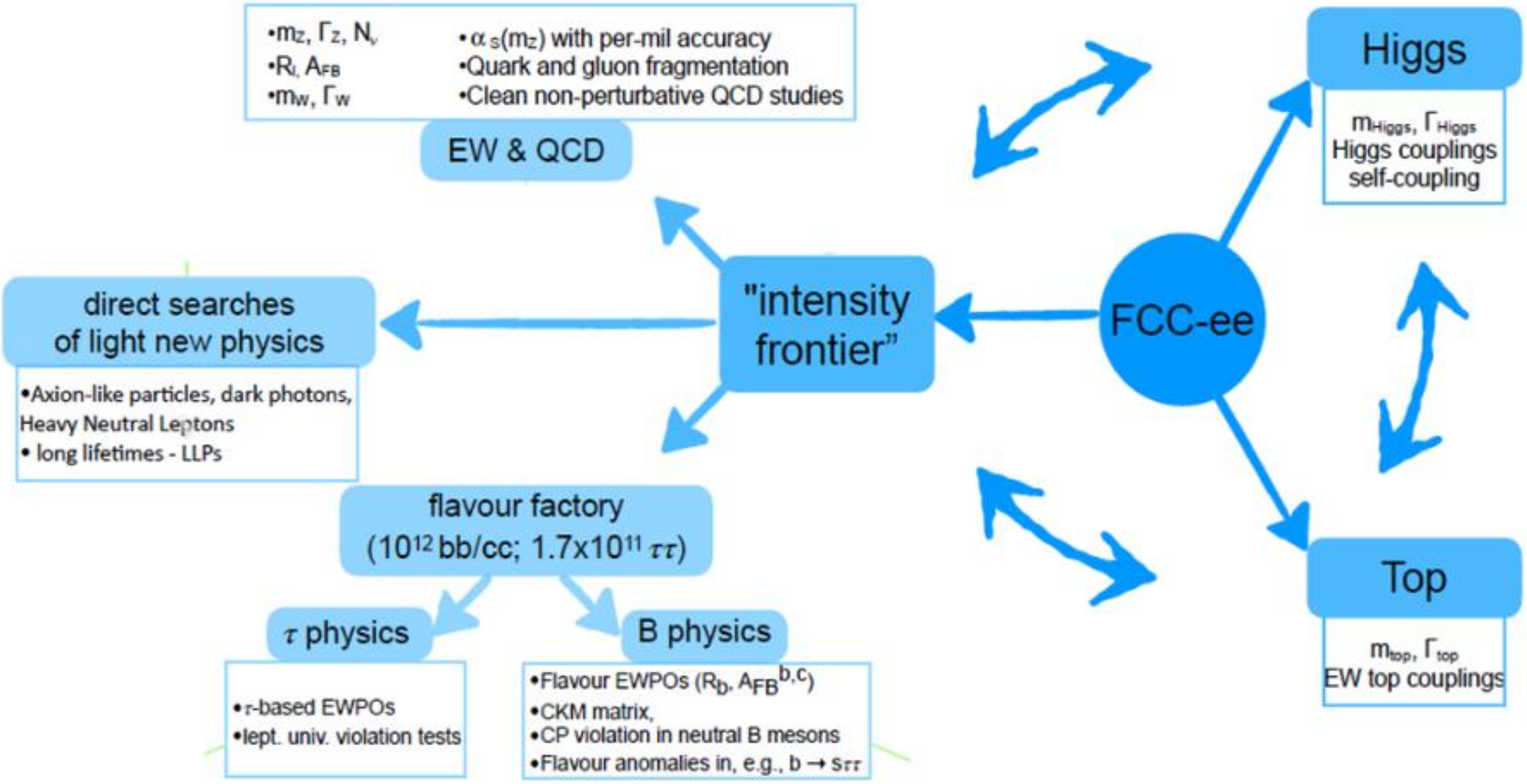
- Different runs at different centre of mass energies.





FCCee physics program

Christophe Grojean



[Christophe Grojean]

FCCee physics program

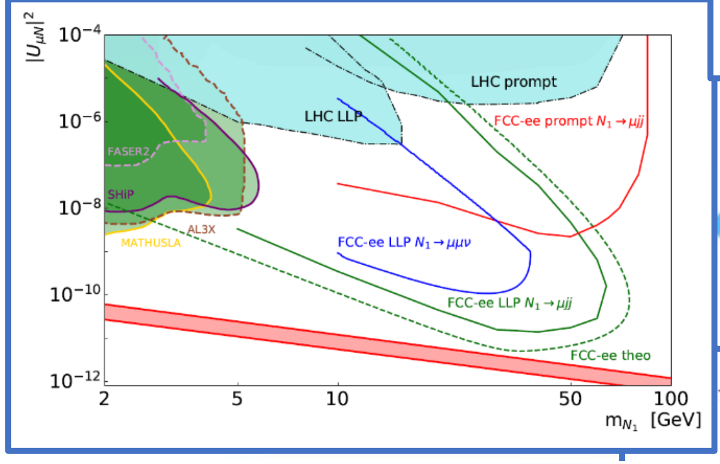
FCC feasibility studies, link.

EW & QCD

	Current knowledge			FCC uncertainties Stat	Syst
Γ_Z (keV)	2 495 500	±	2300	**4**	12
$\sin^2\theta_W^{\rm eff}$ ($\times10^6$)	231,480	±	160	**1.2**	1.2
$\alpha_S(m_Z^2)$ ($\times10^4$)	1 196	±	30	**0.1**	1
$\sigma^0_{\rm had}$ ($\times10^3$) (nb)	41 480.2	±	32.5	**0.03**	0.8
R_b ($\times10^6$)	216 290	±	660	**0.25**	0.3
$A_{FB}^{b,0}$ ($\times10^4$)	992	±	16	**0.04**	0.04

•mZ,
•R, A
•mW,

direct searches of light new physics



"intensity frontier"

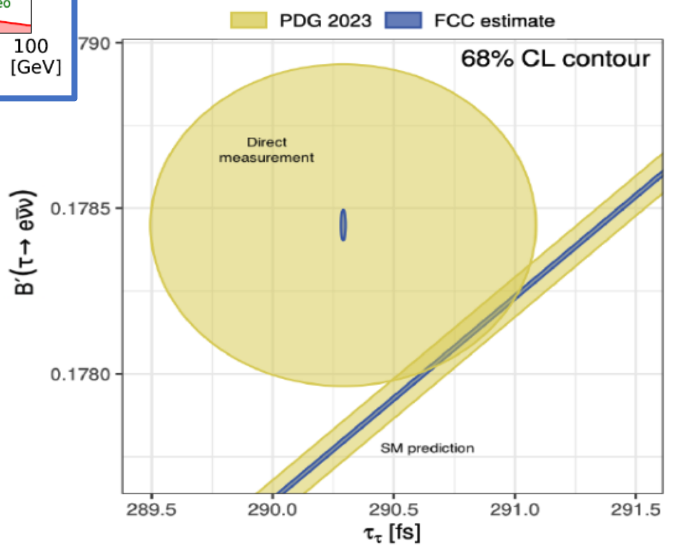
FCC-ee

Higgs

Coupling	HL-LHC	FCC-ee	FCC-ee + FCC-hh
κ_Z (%)	1.3*	0.10	0.10
κ_W (%)	1.5*	0.29	0.25
κ_b (%)	2.5*	0.38 / 0.49	0.33 / 0.45
κ_g (%)	2*	0.49 / 0.54	0.41 / 0.44
κ_τ (%)	1.6*	0.46	0.40
κ_c (%)	–	0.70 / 0.87	0.68 / 0.85
κ_γ (%)	1.6*	1.1	0.30
$\kappa_{Z\gamma}$ (%)	10*	4.3	0.67
κ_t (%)	3.2*	3.1	0.75
κ_μ (%)	4.4*	3.3	0.42
$\lvert\kappa_s\rvert$ (%)	–	$^{+29}_{-67}$	$^{+29}_{-67}$
Γ_H (%)	–	0.78	0.69
$\mathcal{B}_{\rm inv}$ (<, 95% CL)	1.9×10^{-2} *	5×10^{-4}	2.3×10^{-4}
$\mathcal{B}_{\rm unt}$ (<, 95% CL)	4×10^{-2} *	6.8×10^{-3}	6.7×10^{-3}

[Christophe Grojean]

flavour factory (10^{12} bb/cc; 1.7×10^{11} $\tau\tau$)



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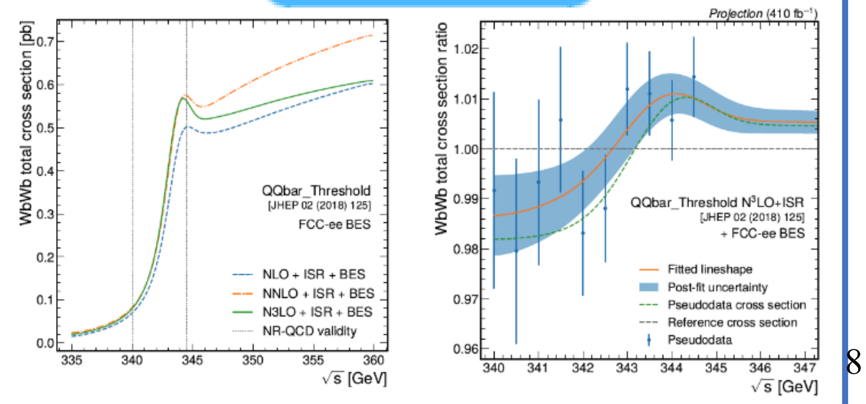
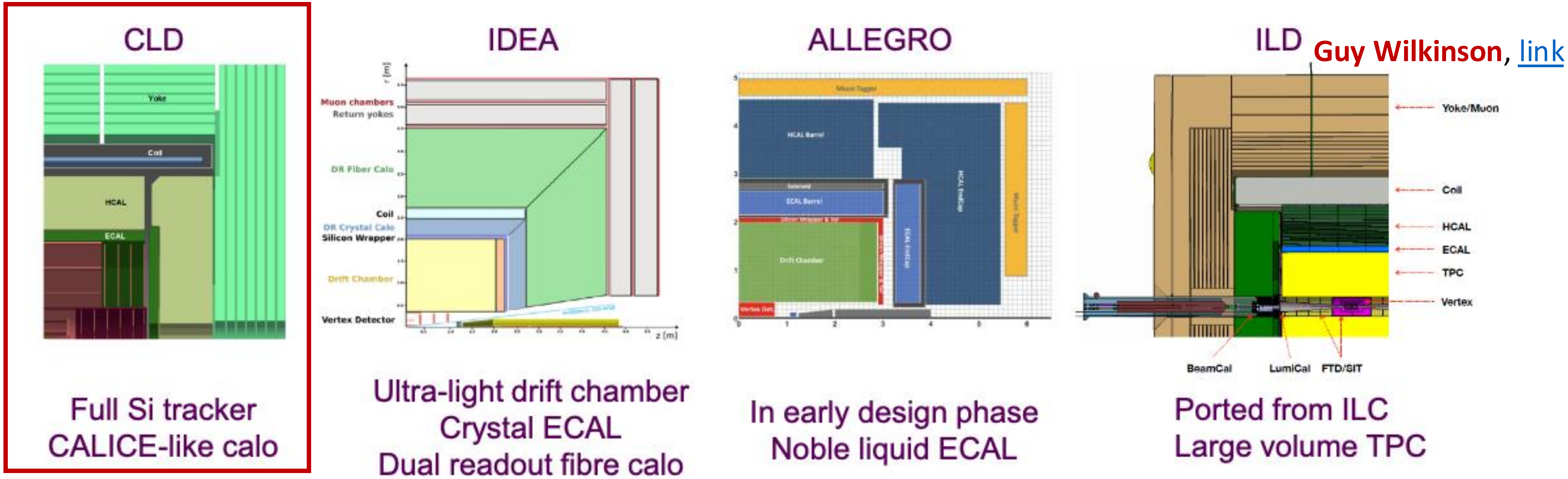


FCCee detector concepts

- Existing detector concepts (not collaborations).
- Different technologies choices, in particular for Tracker, PID and calorimetry.

Only with FullSim available

Guy Wilkinson, link

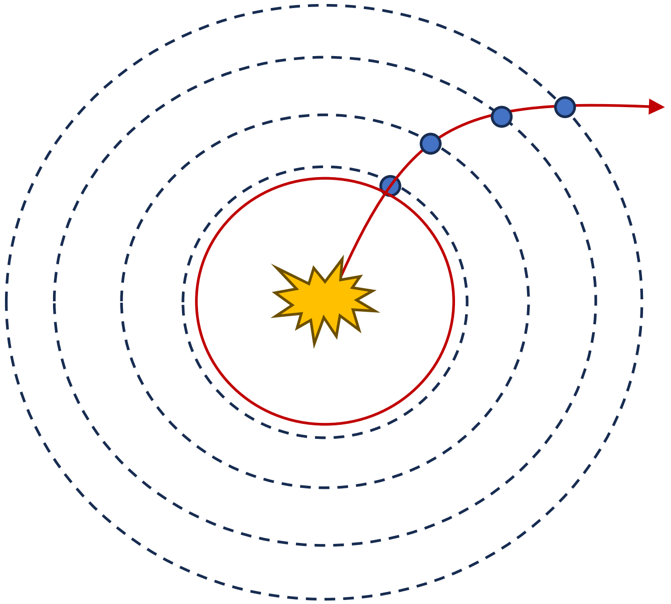


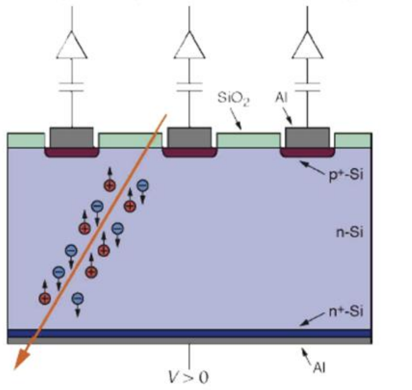
- Vertex detectors are usually based on the same technologies (MAPS), but might have different chips designs, mechanics or cooling approaches.

Tracking system : generalities

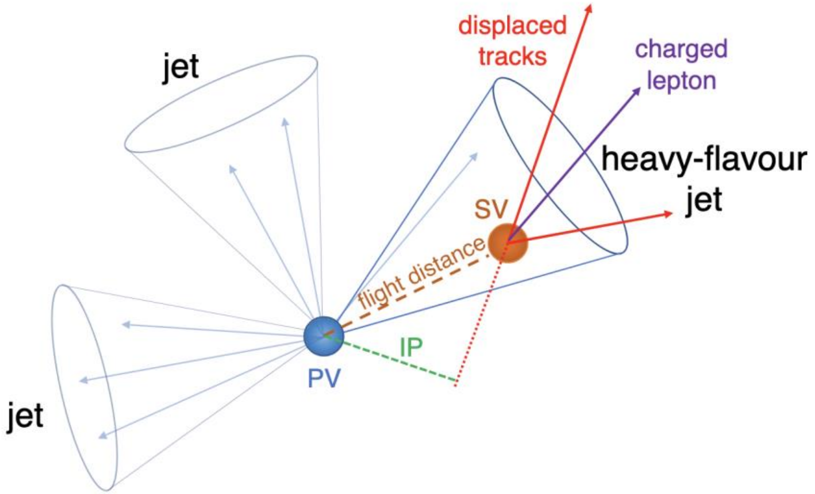
- Reconstruction of the trajectories of charged particles.

- Usually composed of 2 parts :
  - Inner Tracker, of Vertex Detector=>
    - Precise measurements of the impact parameters, (secondary) vertex reconstruction,
    - Based on silicon semi-conductor
  - Outer Tracker :
    - Complete detector, resolution of transverse momentum and angles,
    - Can be based on silicone detector, gaseous detector.





- Positions (hits) of detection of the particles are linked together to reconstruction trajectories : tracking algorithms.

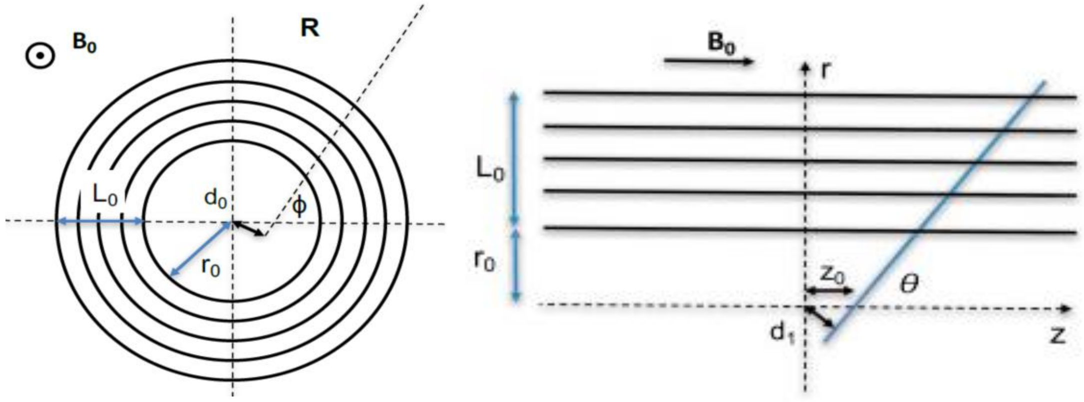


- Tracks are key elements of events reconstruction:
  - Leptons reconstruction,
  - Particle flow,
  - Jets reconstruction,
  - Flavour identification.

Vertex detector specifications and performances

Main parameters of tracks resolution

Drasal, Riegler, https://doi.org/10.1016/j.nima.2018.08.078



$$\Delta d_0|_{res.} \approx \frac{3\sigma_{r\phi}}{\sqrt{N+5}}\sqrt{1+\frac{8r_0}{L_0}+\frac{28r_0^2}{L_0^2}+\frac{40r_0^3}{L_0^3}+\frac{20r_0^4}{L_0^4}}$$

$$\Delta d_0|^{opt}_{m.s.} \approx \frac{0.0136\,\mathrm{GeV/c}}{\beta p_T} r_0 \sqrt{\frac{d}{X_0\sin\theta}}\sqrt{1+\left(\frac{r_0}{L_0}\right)+\left(\frac{r_0}{L_0}\right)^2}$$

$$\frac{\Delta p_T}{p_T}\Big|_{res.} \approx \frac{12\,\sigma_{r\phi}\, p_T}{0.3\, B_0 L_0^2}\sqrt{\frac{5}{N+5}}$$

$$\frac{\Delta p_T}{p_T}\Big|_{m.s.} \approx \frac{0.0136\,\mathrm{GeV/c}}{0.3\beta\, B_0 L_0}\sqrt{\frac{d_{tot}}{X_0\,\sin\theta}}$$

$$d_{tot}/X_0 = (N+1)d/X_0$$

- Relevant parameters for tracks resolution $(\Delta d_0, \Delta p_T/p_T)$:
  - Single point resolution $\sigma_{r-\varphi}$,
  - Material budget $(m.s.)$,
  - Radius of the innermost measured point r_0,
  - Level arm (L_0).
- Remarks,
  - With existing single point resolution, performance strongly dependant on r_0 and material budget,
  - Multiple scattering impact reduced with lower r_0,
  - d_0 resolution improves with the number of layers N, $\Delta p_T/p_T$ proportional to $\sqrt{1/N}$,
  - Strong dependence of $\Delta p_T/p_T$ to the level arm (L_0).

FCCee

$$\sigma_{d_0} = a \oplus \frac{b}{p\, sin^{3/2}\theta} \qquad b \sim r_0\sqrt{material} \qquad a \sim \sqrt{r_0}$$

$a \approx 5\ \mu m;\ \ b \approx 15\ \mu m$

ALICE ITS2

$\Delta d_0|_{m.s.} = 22, 4.4, 2.2\,\mu\mathrm{m}$ for $p_T = 1, 5, 10\,\mathrm{GeV/c}$

Material budget is a key parameter !

Vertex sensor specifications

Spatial resolution per layer	$\simeq 3$	μm
Pixel pitch	14-20	μm [1]
read-out time	$\simeq 500$	ns [2]
Power dissipation	$\simeq 20-50$	mW/cm^2
Sensor thickness	$40-50$	μm [3]
Safety factor on particle rate	3	[4]
Maximum Hit rate	75 / 25	MHz/cm^2 [5]
Maximum Hit rate	22.5×10^{-3} / 7.5×10^{-3}	$hits/mm^2/BX$ [5]
Assumed cluster multiplicity	5	
Fired pixel rate	375 / 125	MHz/cm^2 [5]
Fired pixel rate	0.33 / 0.11	$fired\ pixels/mm^2/BX$ [5]
Occupancy/pixel/read-out	3.45×10^{-3} / 1.15×10^{-3}	$/pixel/readout$ [5]
Ionising radiation (1^{st} layer)	30 / 10	$MRad/year$ [5] [6]
Corresponding Fluence	$\simeq 1.8 \times 10^{14}$ / 6×10^{13}	$n_{eq(1\ MeV)}/year$ [5] [7]

Depends on charge shareing and encoding

Balance between power dissipation and particle rate

To be compatible with air cooling

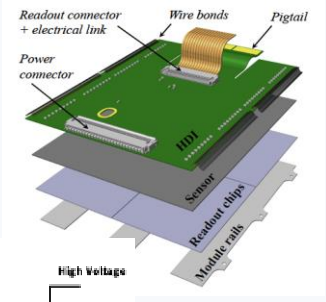
Reduced material budget, allows for bending

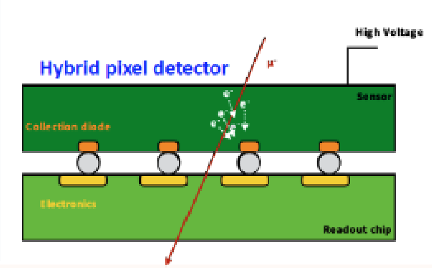
Related to max particle rates at the Z energy

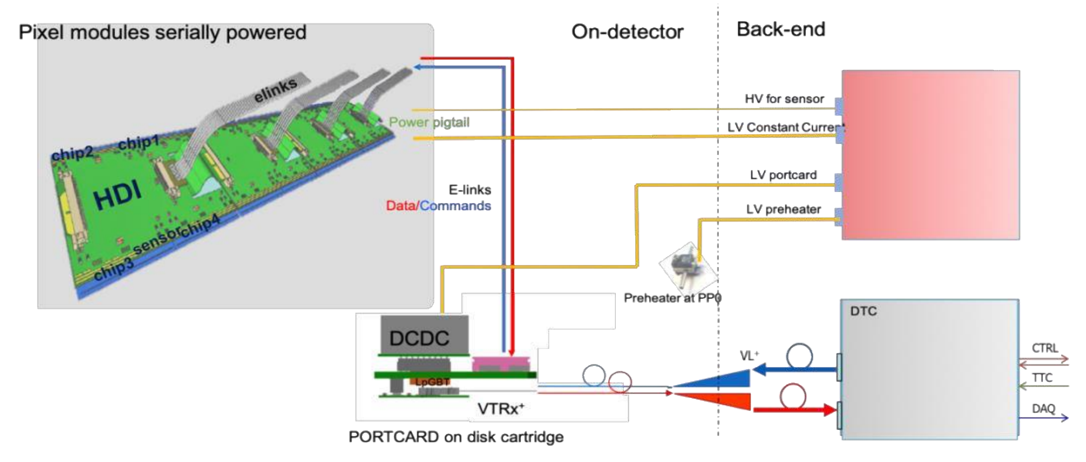
Expected max fluence per year

Vertex/Pixel detector technologies

CMS-IT, Pixel Hybrids (ex.)



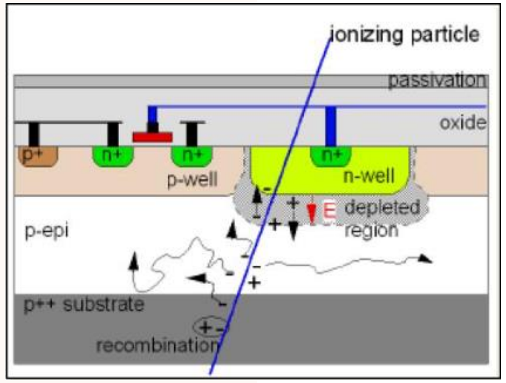


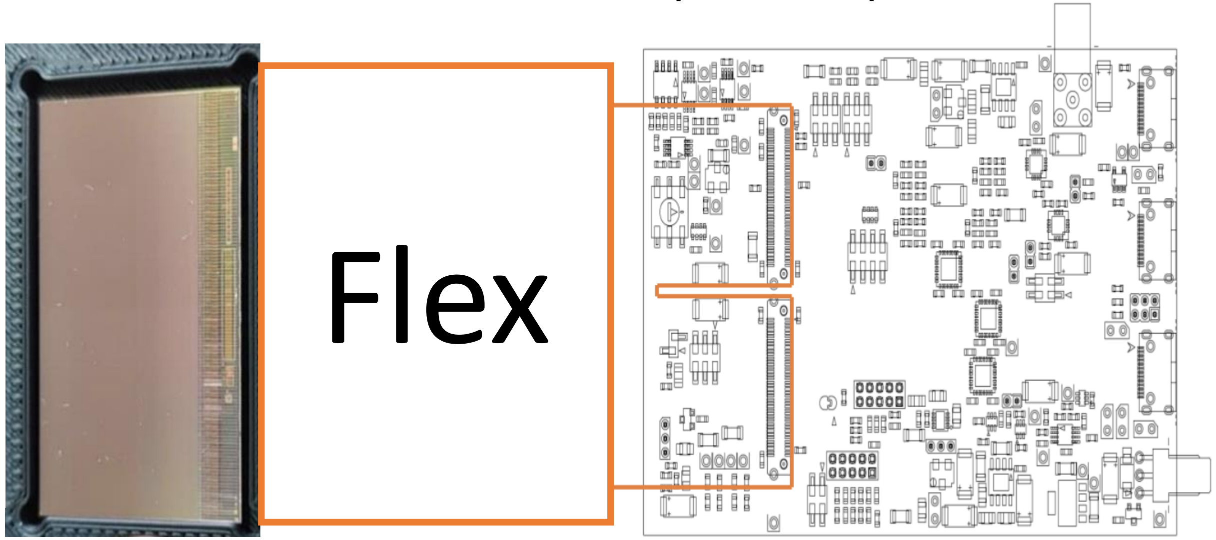


Pixel module

- 3D and planar sensors, with 2 or 4 CROCs.
- HDI : electrical connection (serial powering),
- Optical conversion located on port-cards.

- **Mimosis**, Monolithic Active Pixel Sensor (MAPS)





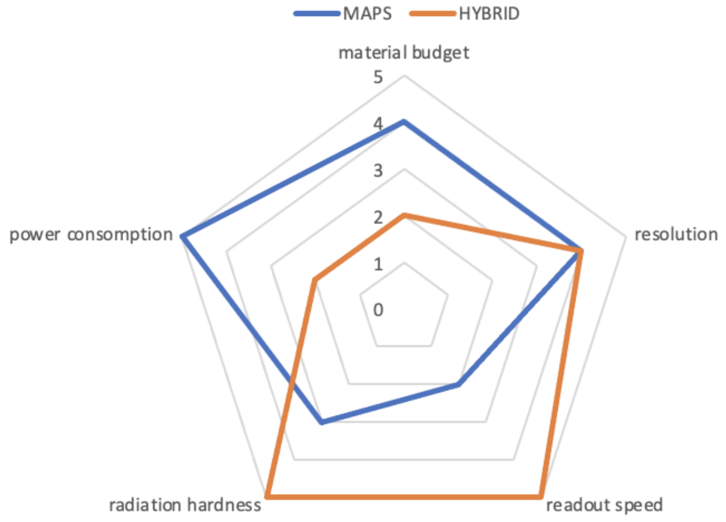
MAPS sensor

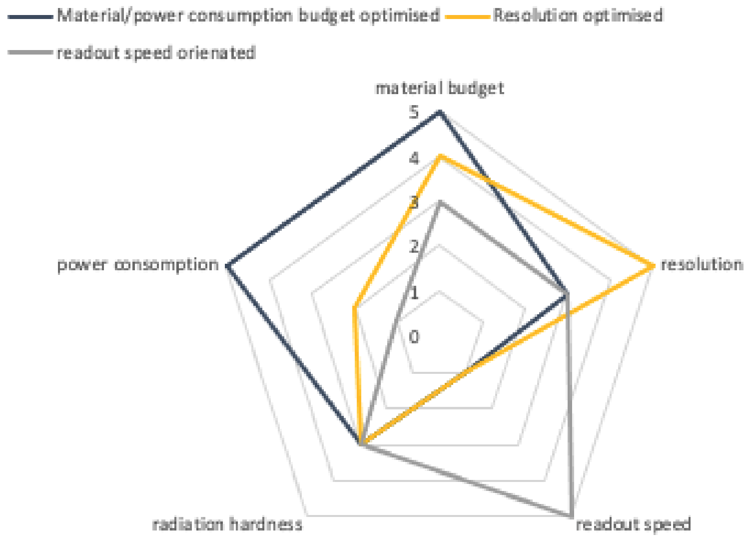
- Integrating sensor and readout on the same silicon substrate,
- Connection with the back-end board through a flex, wire-bonded to the sensor.

Vertex sensor specifications

- Its all about balance
  - Higher resolution (pitch/encoding) => increase power consumption => requires stronger cooling => increase of material budget.
- Hybrids pixel modules developed for (HL)-LHC
  - high radio-tolerance,
  - resistance to SEU,
  - sustain high rates of particles,
  - large material budget,
  - large power consumption (liquid cooling).
- CMOS-MAPS based technologies :
  - High granularities, high resolution,
  - Low power consumption (air cooling possible ?),
  - (very?) low material budget.
- Qualitative representations (0 to 5), the pictures might change depending on R&D choices.

Qualitative representations

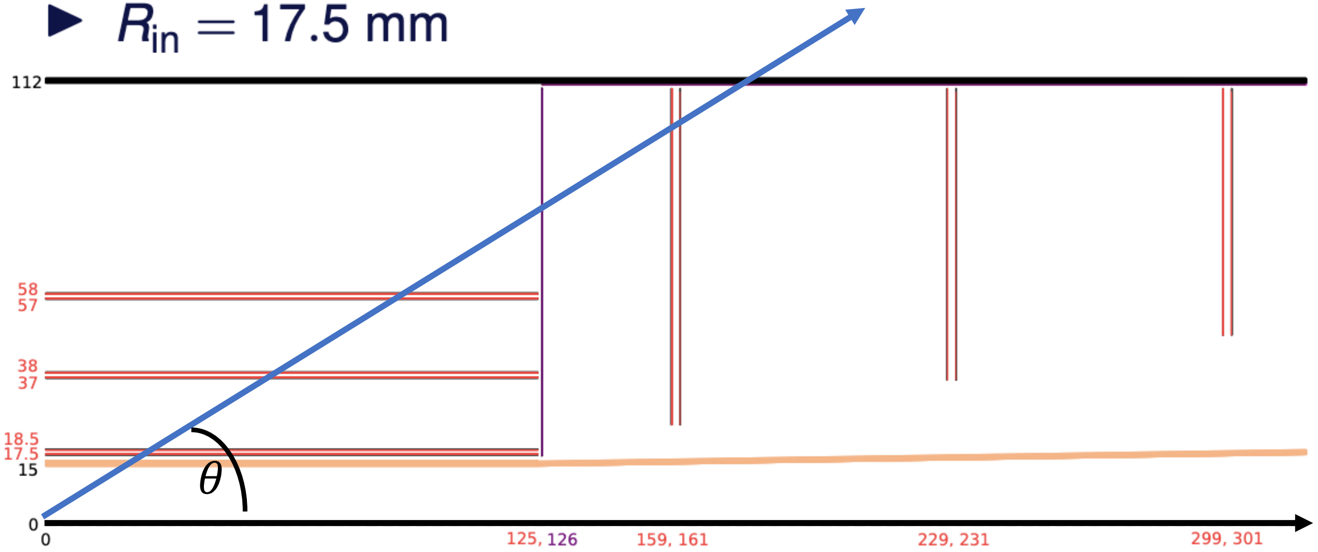


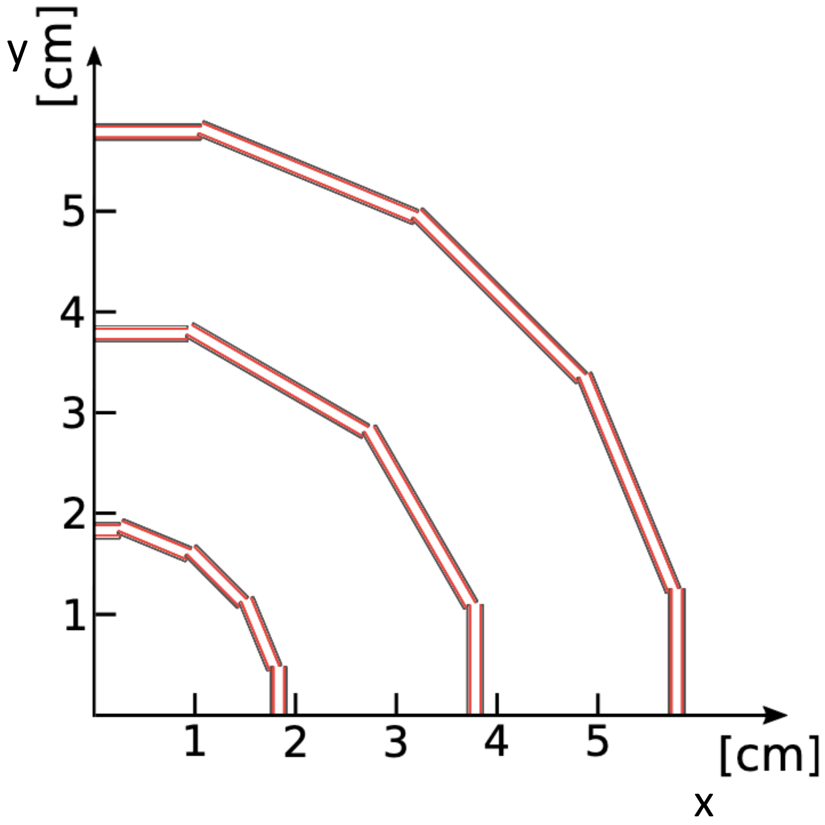


CLD vertexing

A.Sailer, link.

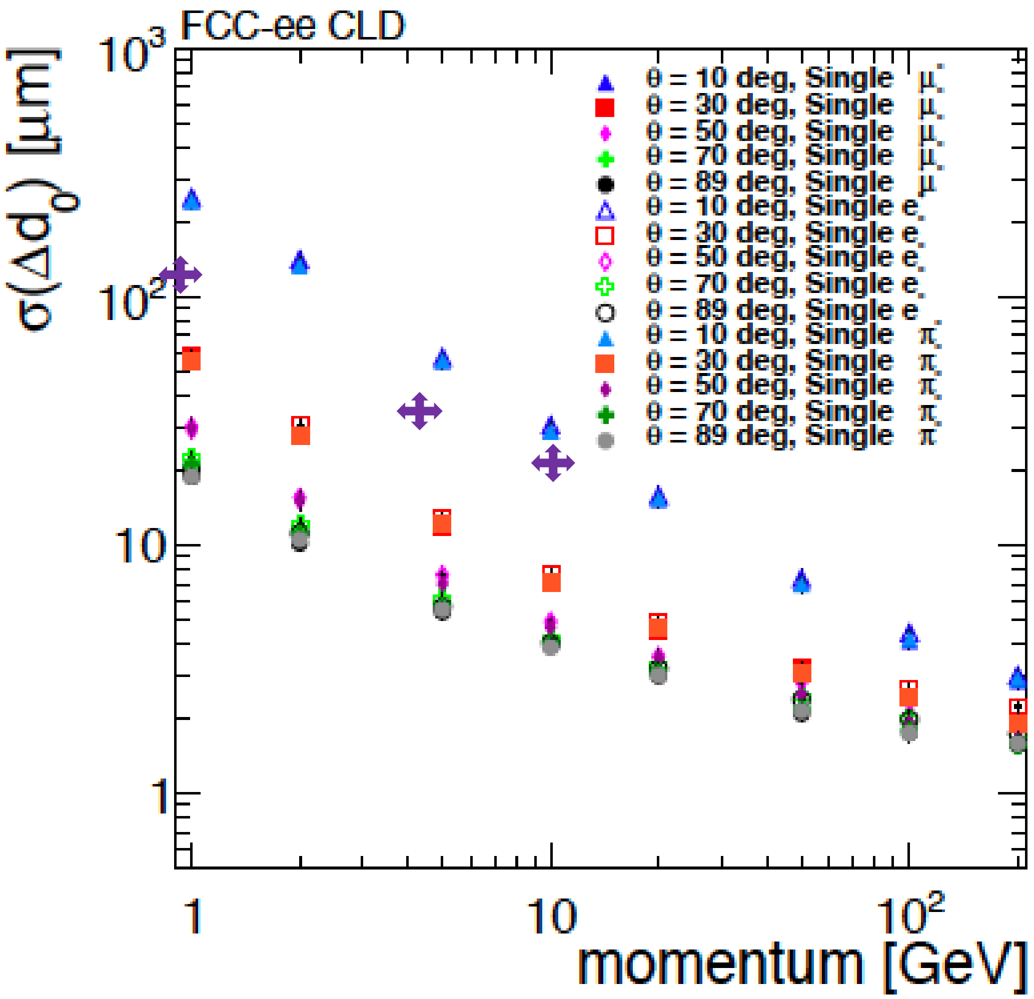
- Silicon vertex detector: precise vertex reconstruction
- $25 \times 25\ \mu m^2$ pixels, 3 μm single point resolution
- 50 μm silicon thickness
- Double layers ($0.3\% X_0$ per detection layer)
- $R_{in} = 17.5$ mm

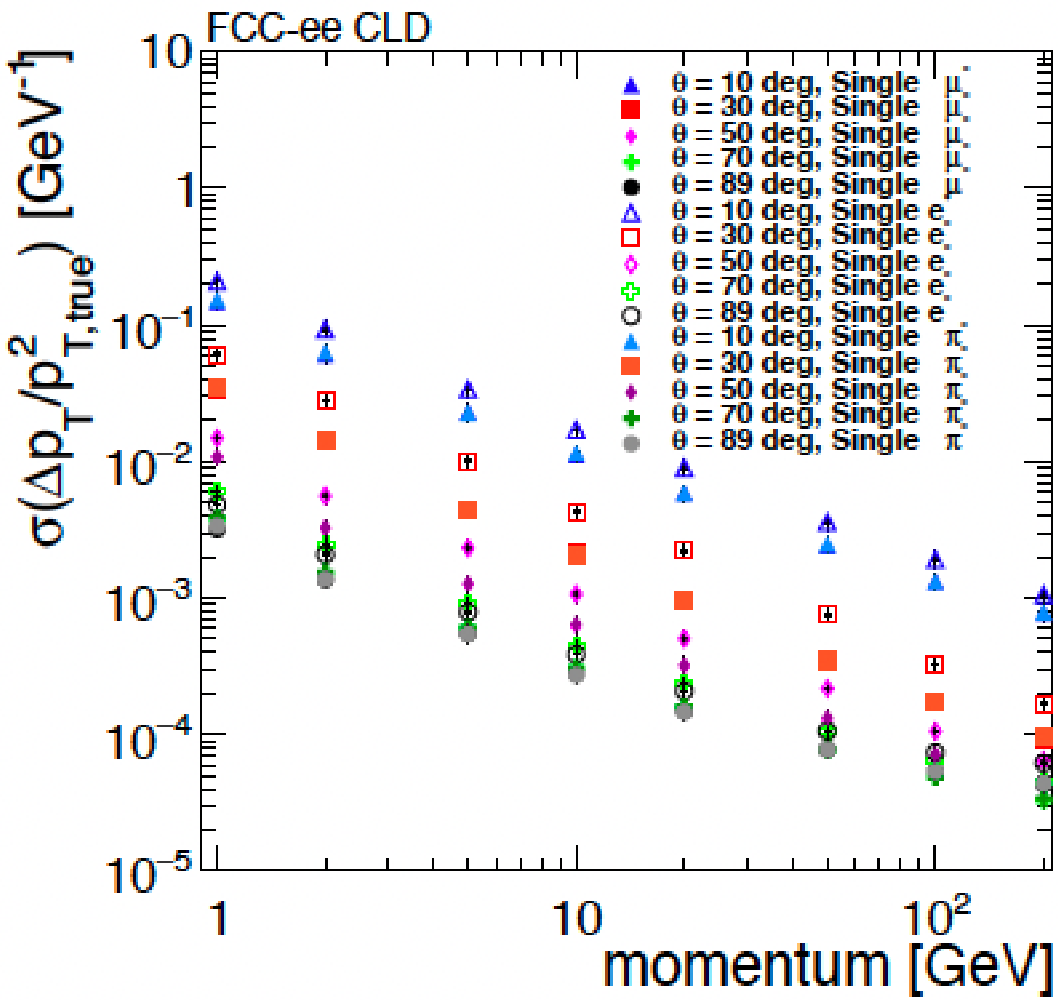




CLD Tracking performance

G.Sadowski

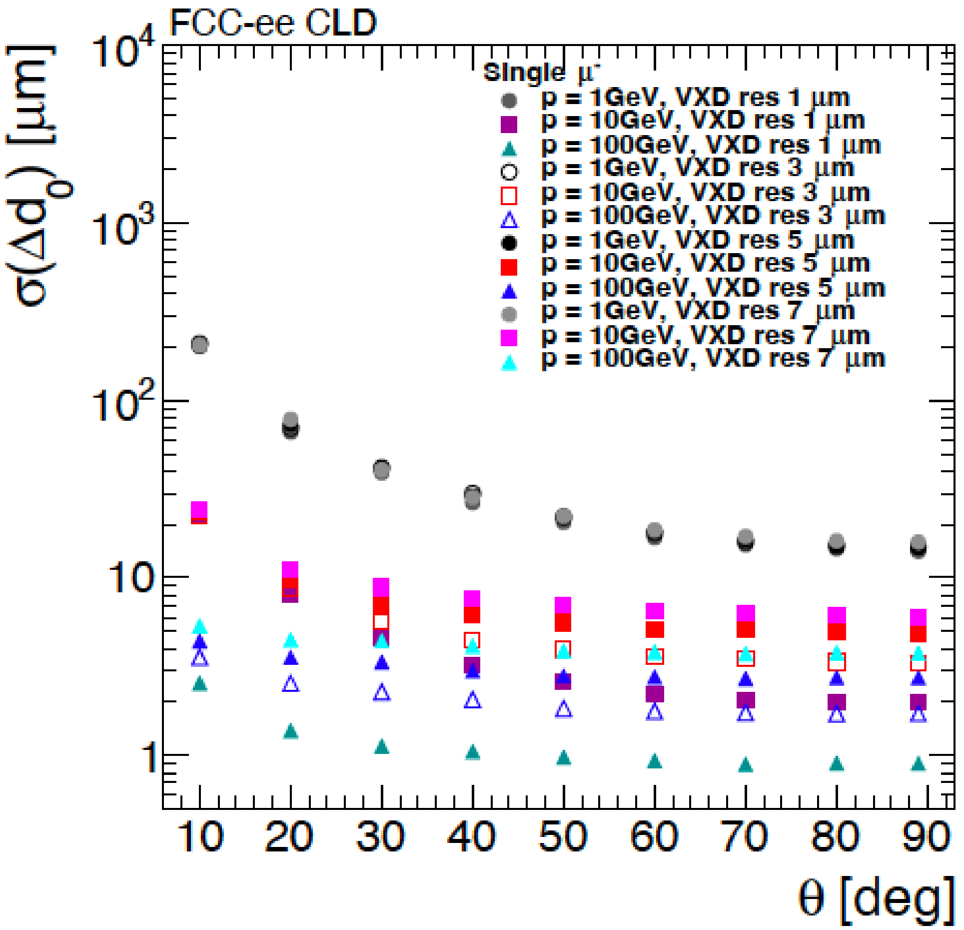


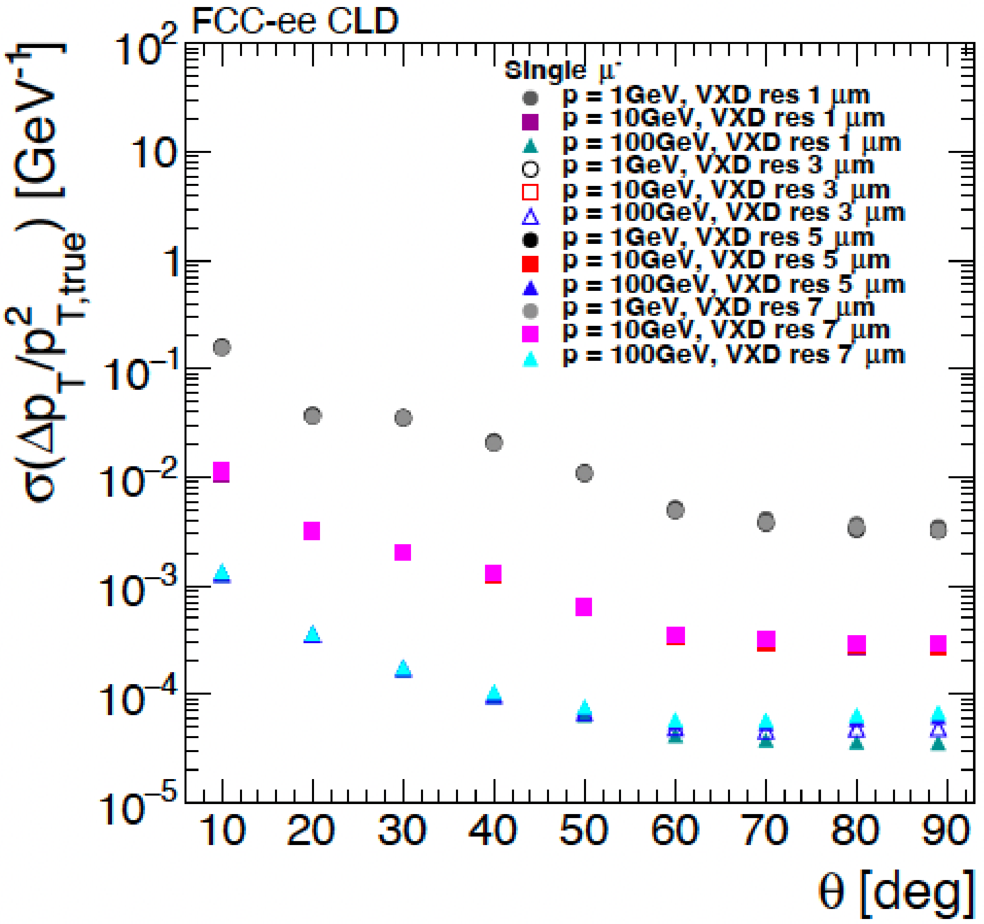


✚ Approximate CMS barrel resolution in 2017

CLD Tracking performance changing single point resolution

G.Sadowski





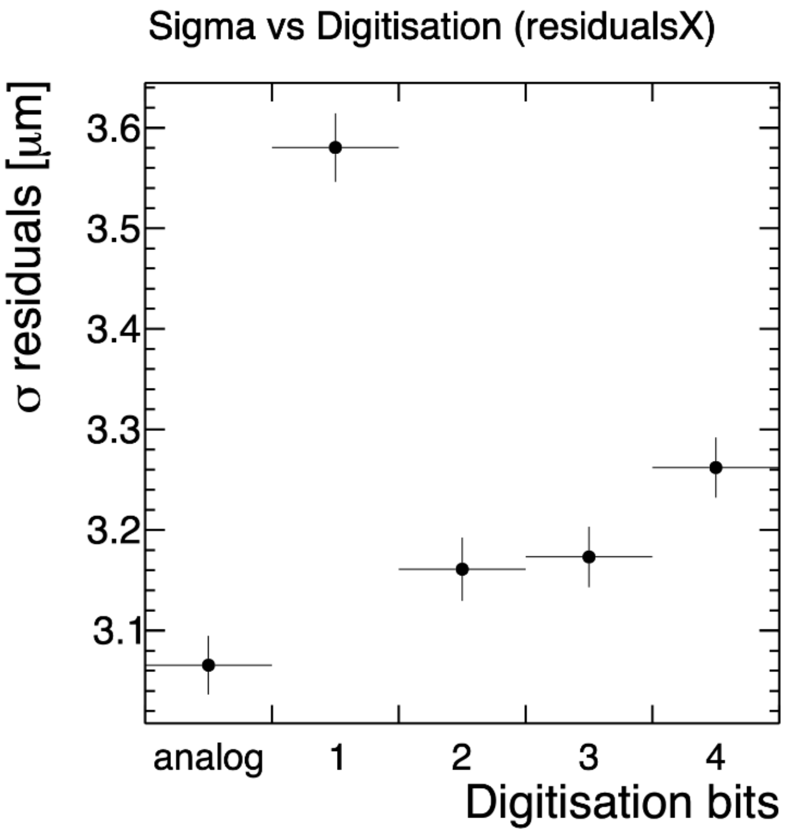
- Single point resolution (smearing) :
  - does not affect significantly the p_T resolution, except for track with high momentum in the central region,
  - Large impact on d_0, except for low momentum track.

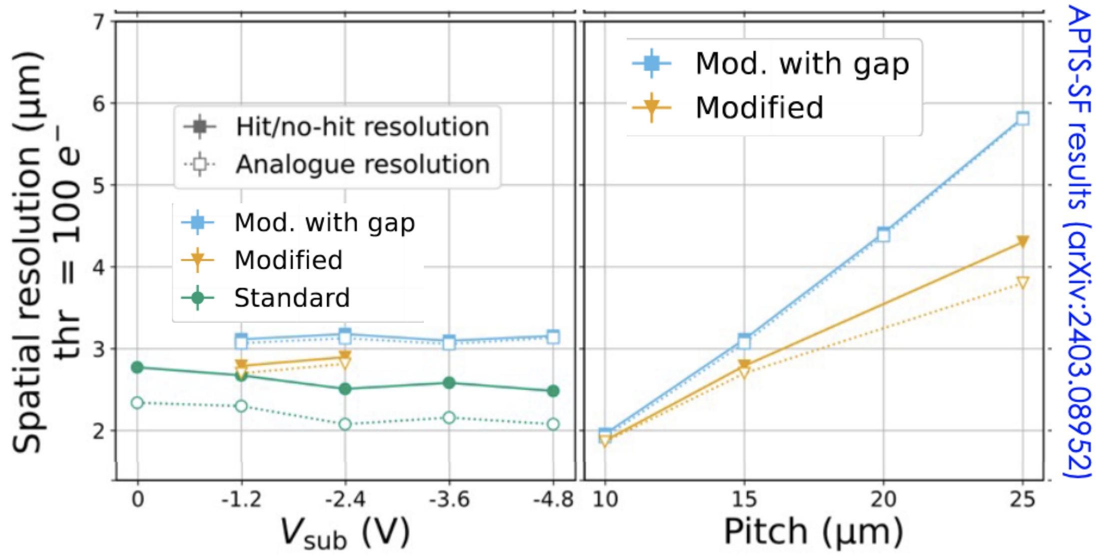
In pixel digisation : resolution vs power consumption

Jérôme Baudot, link.

- Complexity of digitization downscales with pitch => small pitch = 1bit

- Study of position resolution with digitisation of CE-65 analogue output data (Gaëlle Sadowski): 22.5 µm pitch (work in progress)

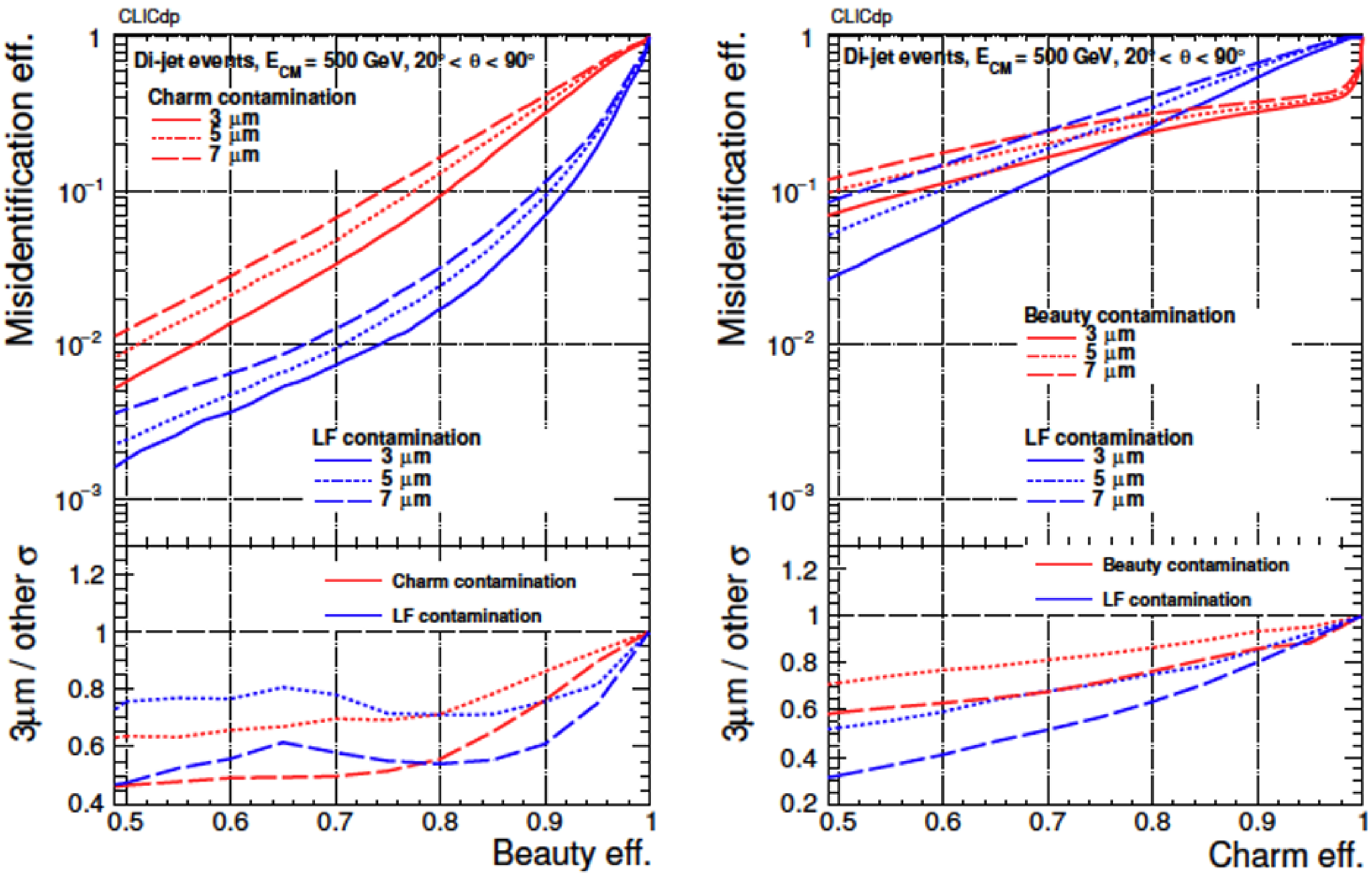




Recipies for σ_{pos} ~ 3 µm

- 1 bit with pitch ≲ 15 µm
- 1.5 to 2 bits with pitch ≳ 20 µm

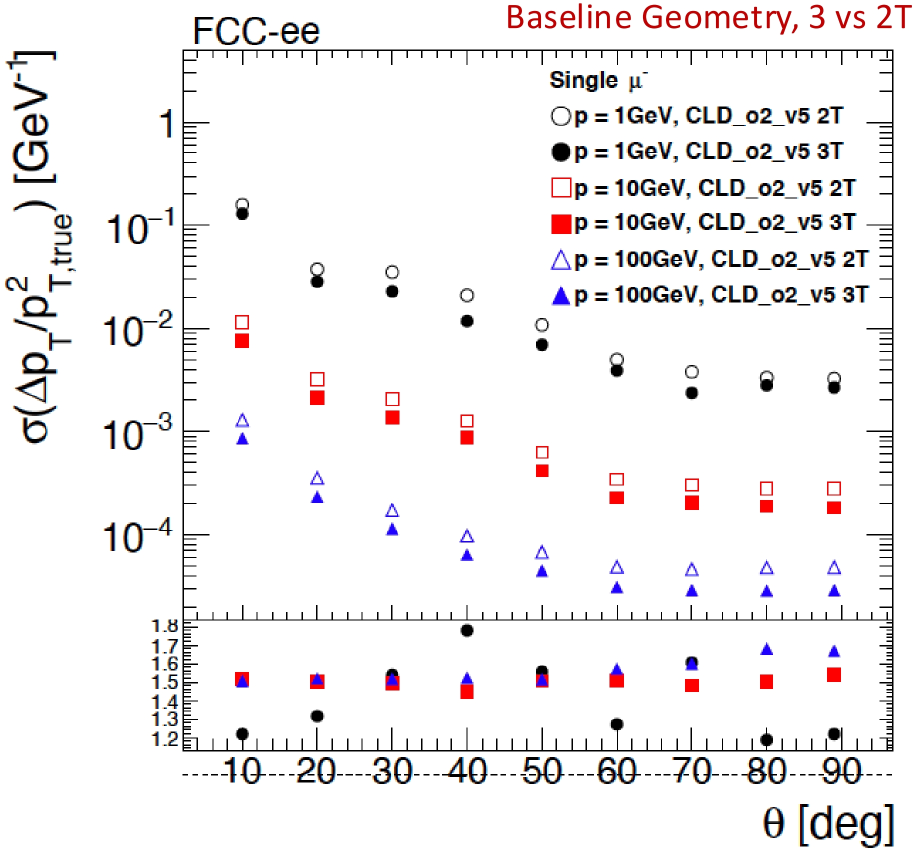
B-tagging performances



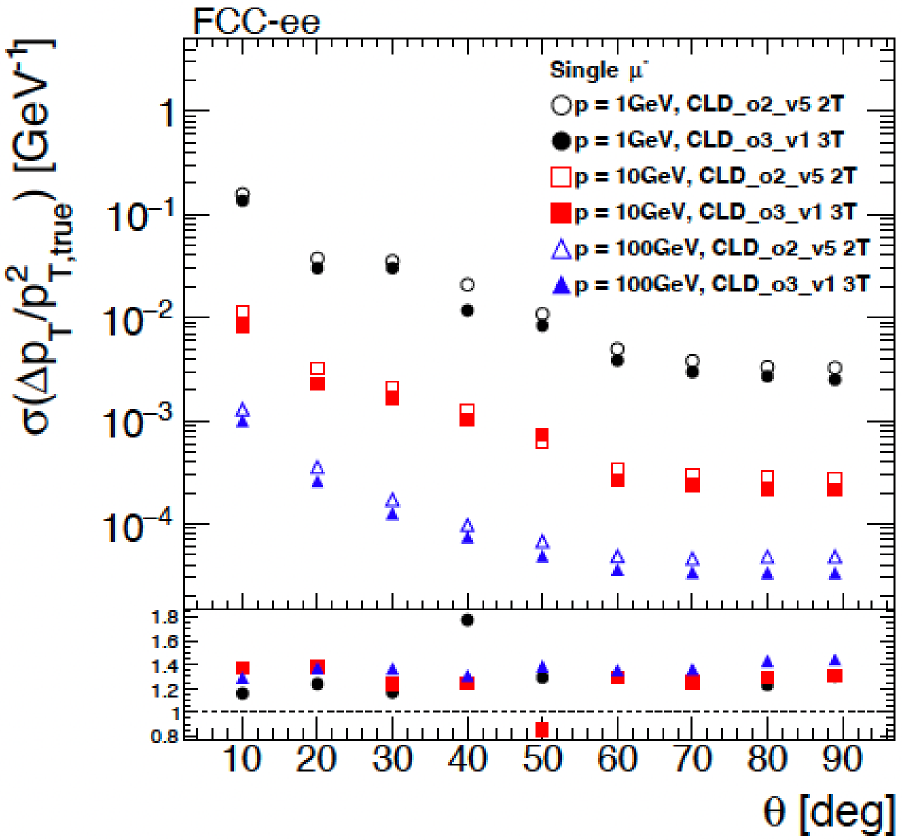
CLD Tracking performance
Impact of the B-field

G.Sadowski

Baseline Geometry, 3 vs 2T



Baseline Geometry@2T vs ~15% reduced L_0@3T

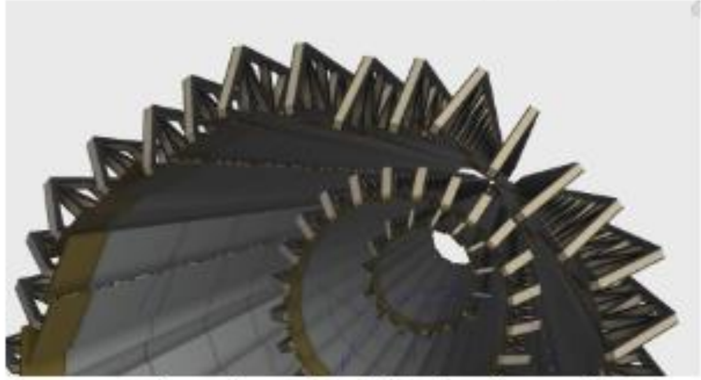


- Dependance on the magnetic field:
  - No impact on d_0,
  - Significant improvements of the track p_T (as expected),
  - Stronger field compensate lower L_0, free space for PID detector

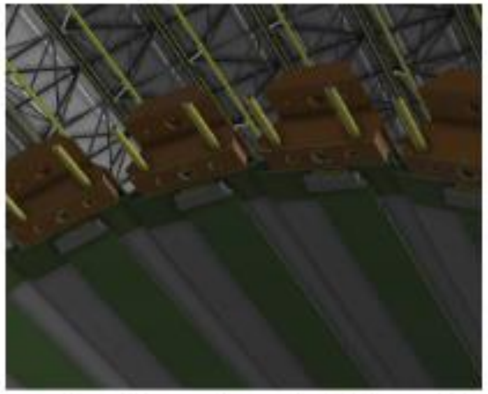
IDEA vertexing

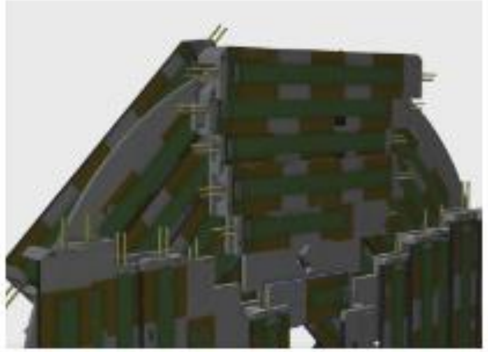
Armin Ilg, link

Vertex detector design by INFN-Pisa, integration in MDI by INFN-LNF

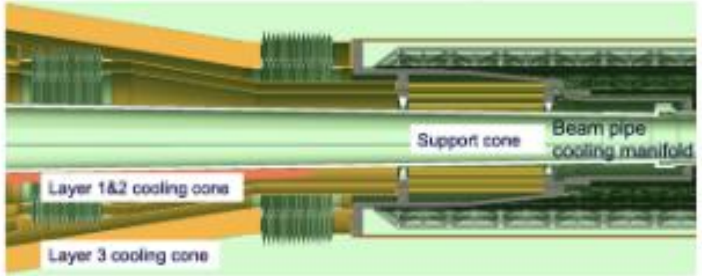


Inner vertex barrel with dual modules of ARCADIA, air-cooled → $\lesssim 50\,\mathrm{mW\,cm^{-2}}$

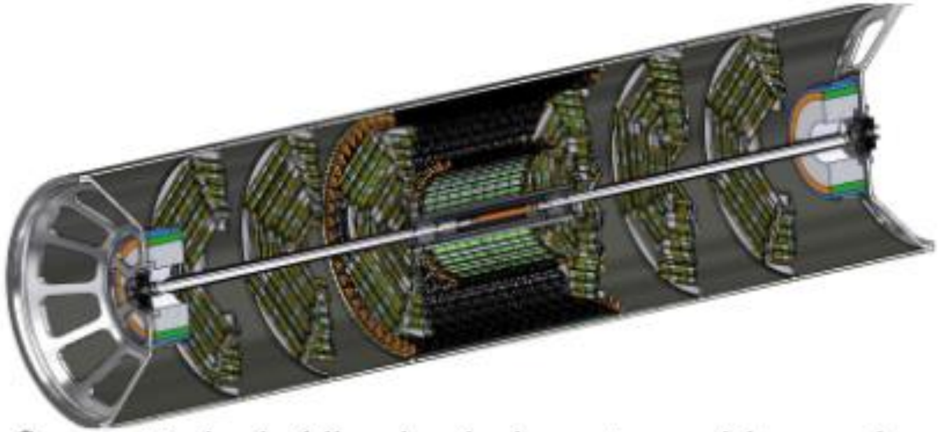




Outer vertex barrel and disks using quad ATLASPix3 DMAPS with $150 \times 50\,\mu\mathrm{m}^2$ pixels, water-cooled

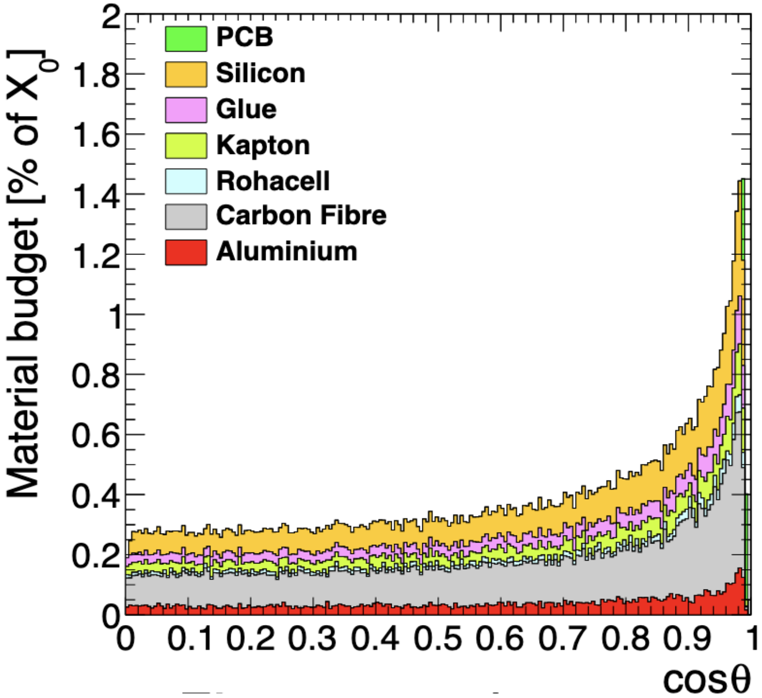


Inner vertex support and cooling cones, first air cooling and transient mechanical analysis results promising

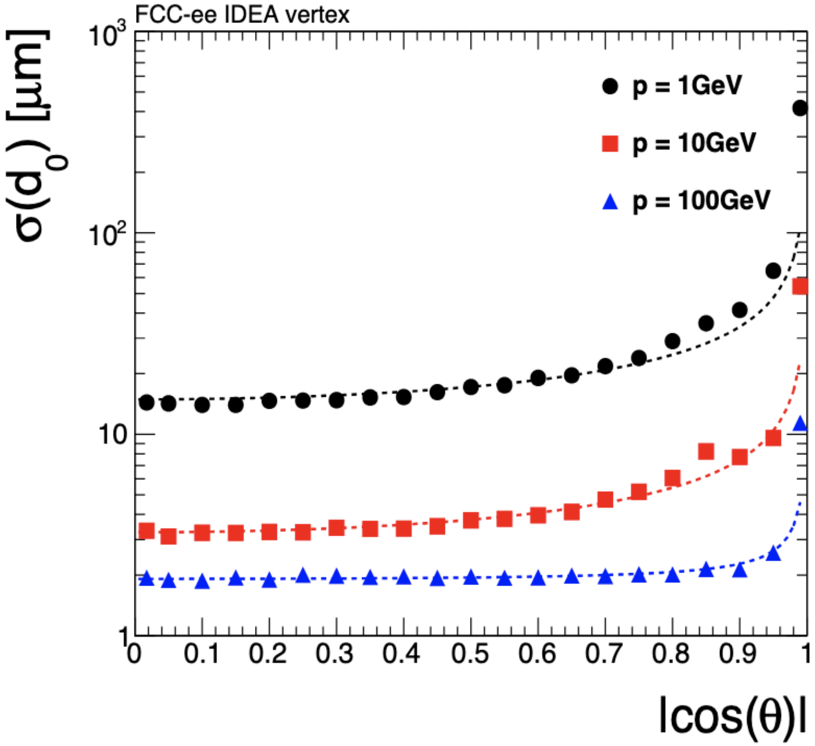


Support tube holding lumical, vertex and beam pipe

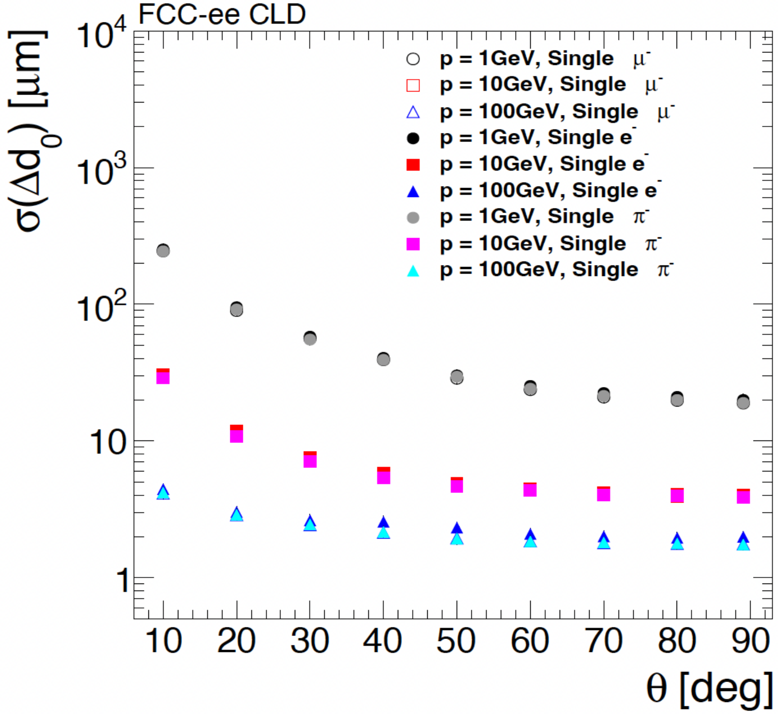
IDEA vertexing



IDEA Integrated into the CLD FullSim



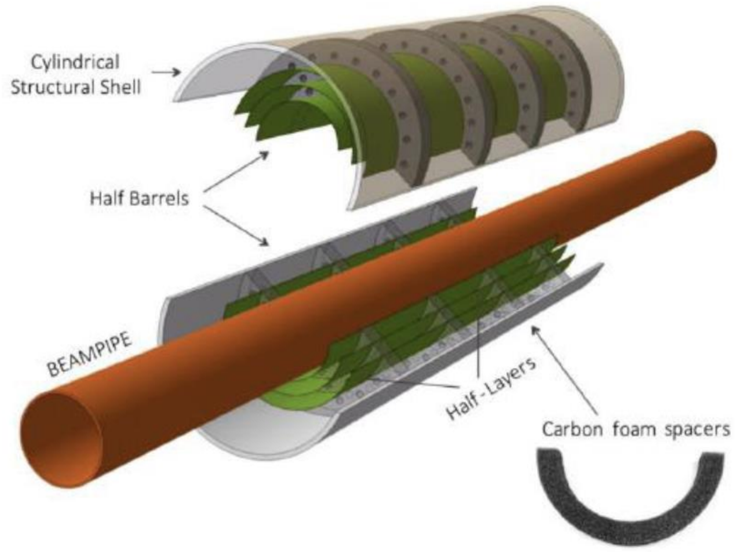
Baseline CLD FullSim



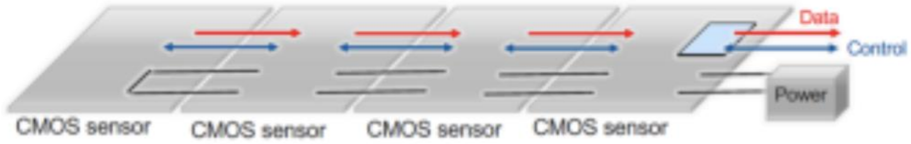
Similar performance, IDEA better at 10 GeV

Pioneer work : Alice ITS3

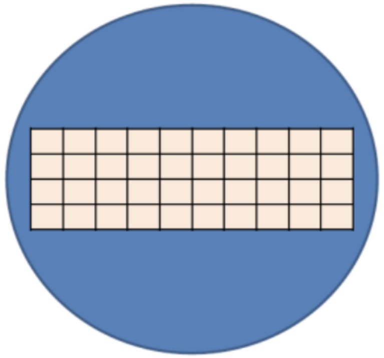
- The beam pipe has a natural cylindric shape:
  - At small radius (innermost layers), it is difficult to approximate a cylinder with the plan surfaces of the sensors,
  - That limits the radius of the inner most layer, increase material budget.

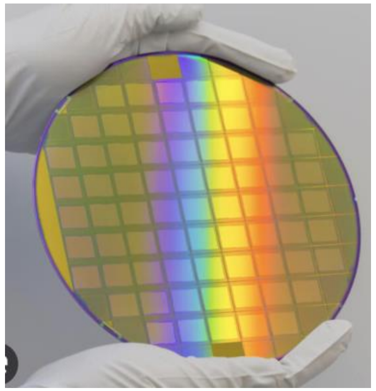


- Proposed solution explored by Alice ITS3:
  - Curve sensors to a radius of 18 mm,
  - Requires sensor thickness of 50 μm,
  - Light mechanics, air cooling,
  - Material budget from ITS2 to ITS3 : 0.3% of X_O to 0.05 % of X_O per inner layers.

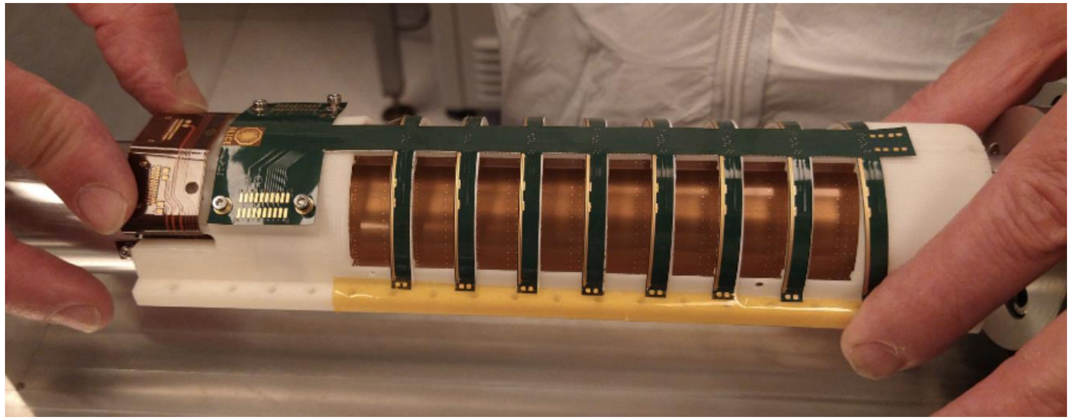


- Sensor "stitching" allows to deport the connections to the end the layer.
  - Yield is potentially an issue.

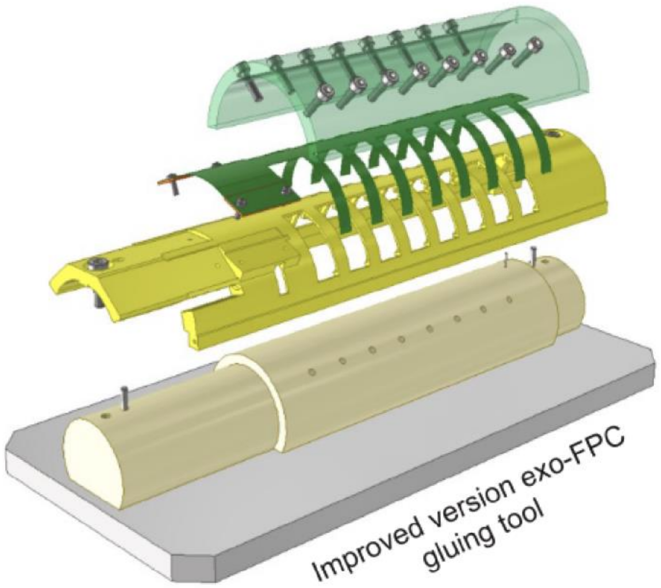


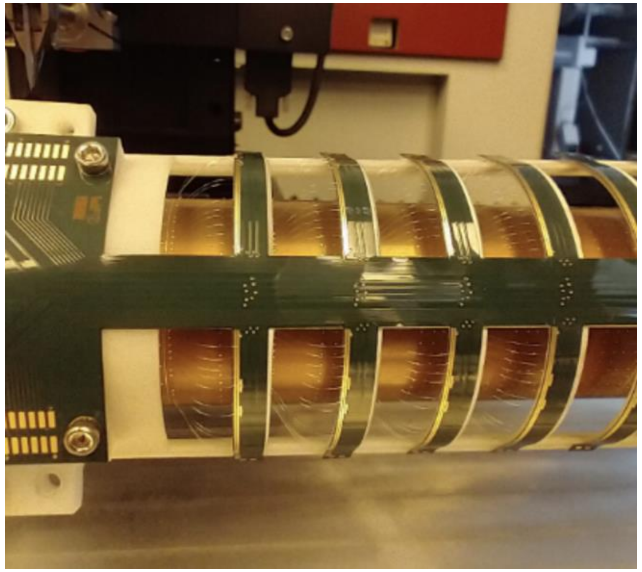


Alice Super-Alpide



- Alice ITS3 backup plan : super-Alpide,
  - Use Alice ITS2 Alpide chips,
  - Use a wafer slice with few Alpide in a lines (9x2),
  - Thinning the slice to 30-40 μm,
  - Bend the slide to the needed radius.





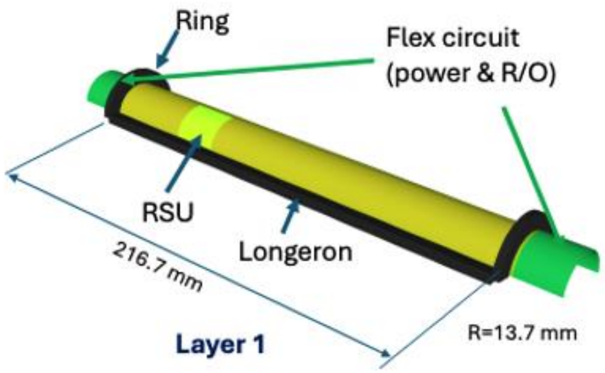
- Requires specific mechanical structure, that allows for wire bonding of all chips.
  - Where we started at IPHC

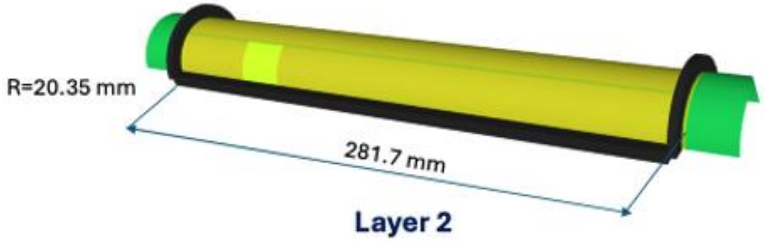
- Location of the bonding pads on the chips makes thinks complicated.

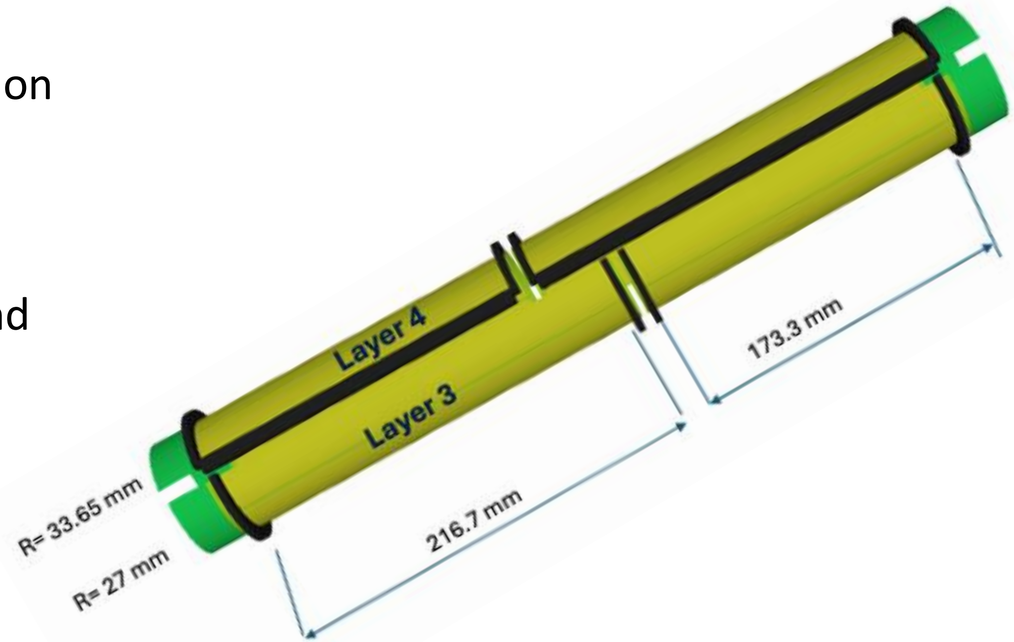
Curved vertex for IDEA

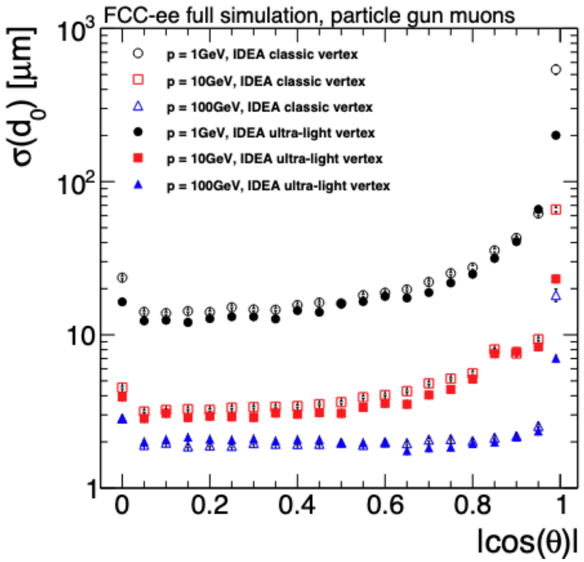
The IDEA detector concept for FCC-ee, link

- New light vertex detector concept for IDEA, based on stitched sensor and curved layers.
- Layer 1 and 2 :
  - 2 half cylinders per layer,
  - Non sensitive regions along the Z direction, compensated with phi rotation of Layer 1 wirh respect to Layer 2
- Layers 3 and 4:
  - 4 half cylinders per layer, for layer 3 and 4,
  - Dead regions in half rings region, compensated by locating them at different Z position.
- Connectivity on both ends of the layers.









Expression Of Interest for a Vertex Detector at FCCee :

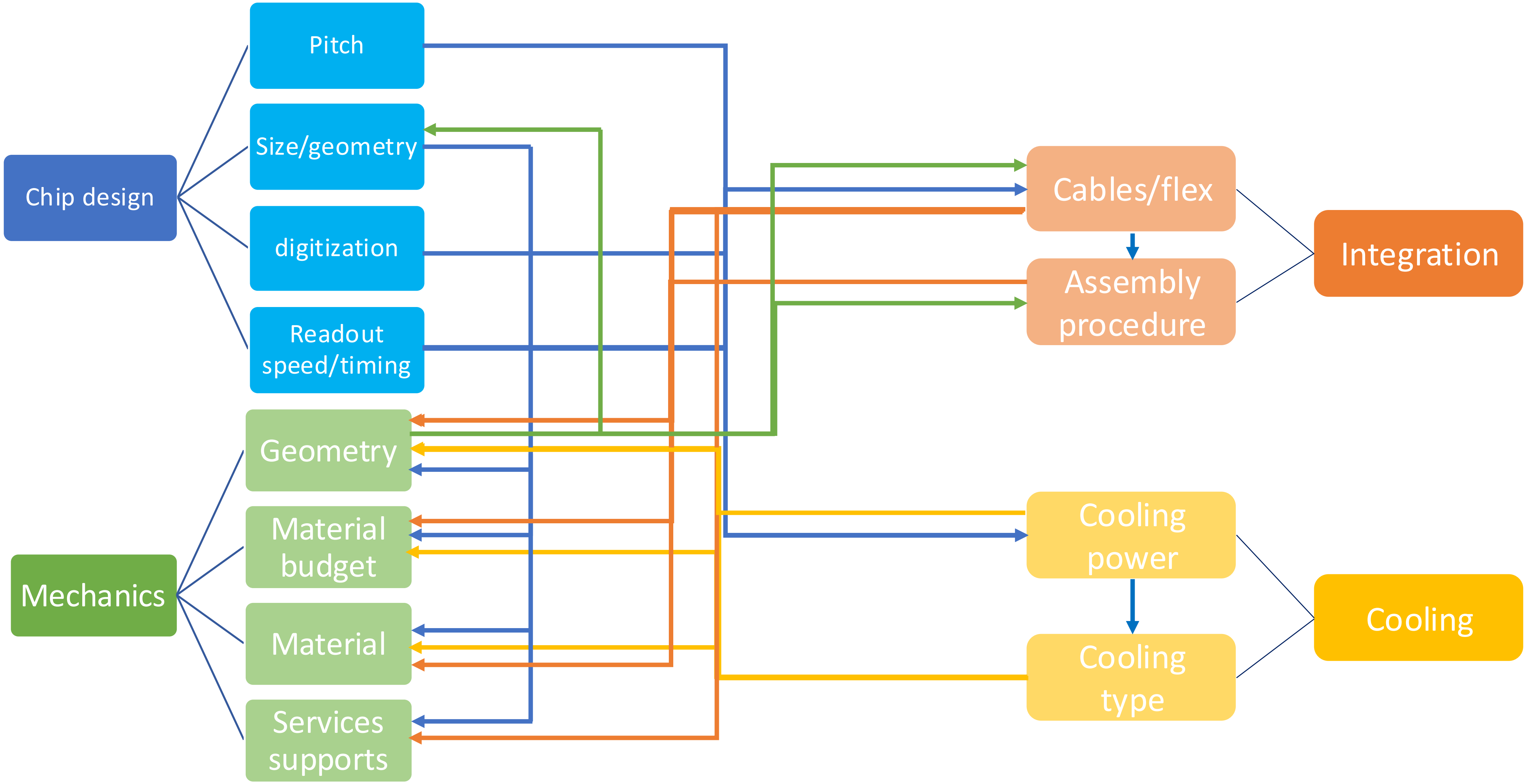
FCC Snail-shape vErtEx Detector (FCC-SEED)

Involved laboratories : IPHC[1], CPPM[2], IP2I[3], LPNHE[4], APC[5], LAPP[6],
Laboratory contact persons: Marlon Barbero[2], Auguste Besson[1], Marco Bomben [5], Gaëlle Boudoul [3], Giovanni Calderini [4], Jessica Levêque[6],
Additional editors: Jérôme Baudot[1], Ziad El Bitar[1], Didier Contardo[3], Fares Djama[2], Elisabeth Petit[2], Serhy Senyukov[1] and
Corresponding author : Jeremy Andrea jeremy.andrea@iphc.cnrs.fr [1]

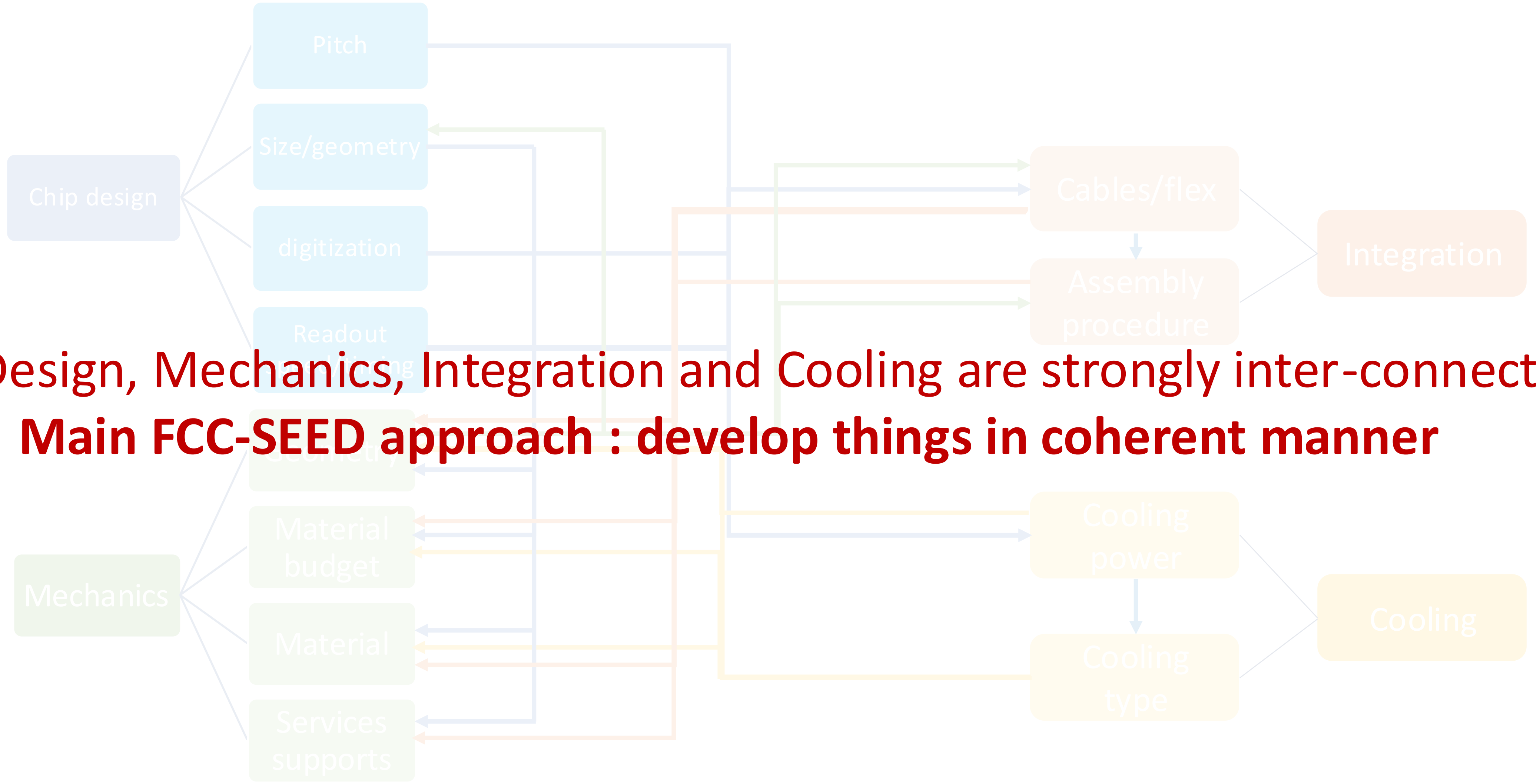
[1]Université de Strasbourg, CNRS, IPHC UMR 7178, Strasbourg, France
[2]CNRS/IN2P3, CPPM, Aix-Marseille University, Marseille, France
[3]Institut de Physique des 2 Infinis de Lyon - CNRS/IN2P3, 69100 Villeurbanne, France
[4]Laboratoire de Physique Nucléaire et de Hautes Énergies UMR 7585, France
[5]laboratoire AstroParticule et Cosmologie, France
[6]Laboratoire d'Annecy de Physique des Particules, France

General Expression of Interests, not yet attached to a specific detector concept

FCC-SEED concept



FCC-SEED concept



Chip Design, Mechanics, Integration and Cooling are strongly inter-connected

Main FCC-SEED approach : develop things in coherent manner

FCC-SEED concept : Octopus

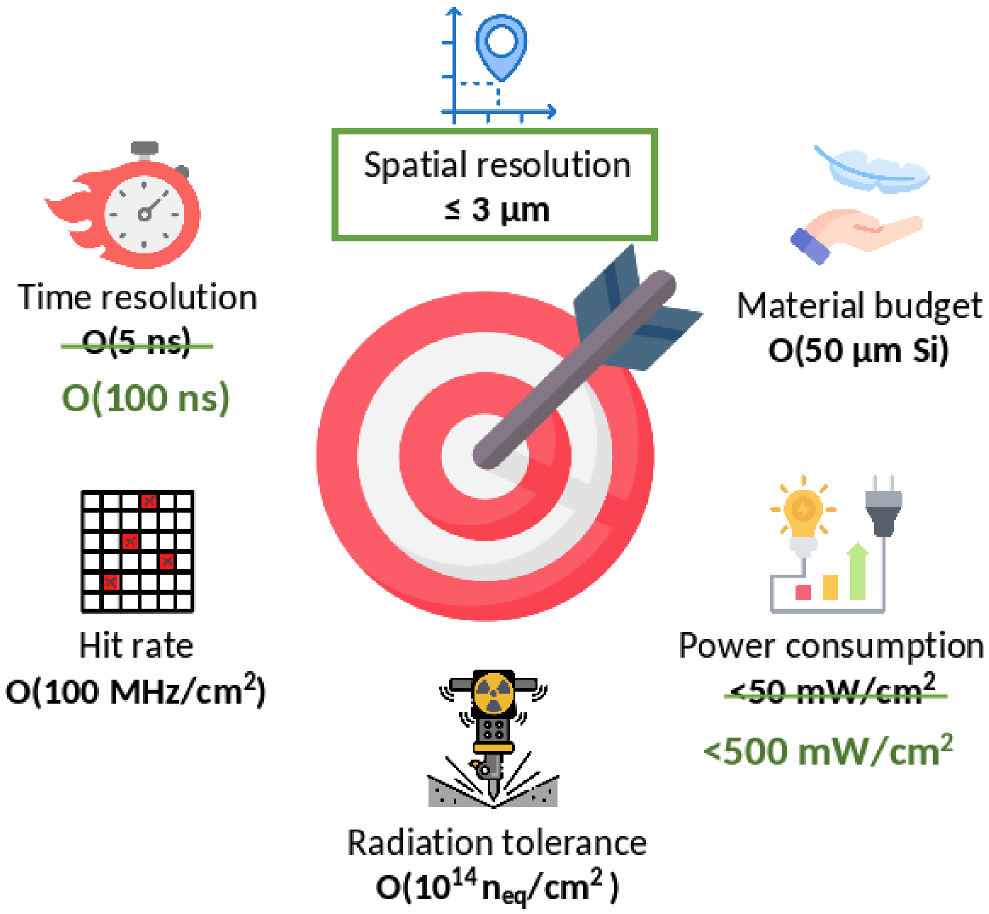
- Octopus : asynchronous readout (pixel grouping) chip,
  - balanced between pitch size and particle rates, lower power consumptions,
  - based on TPSCO 65 nm.

- DRD3 project, 10 labs involved, international collaboration.

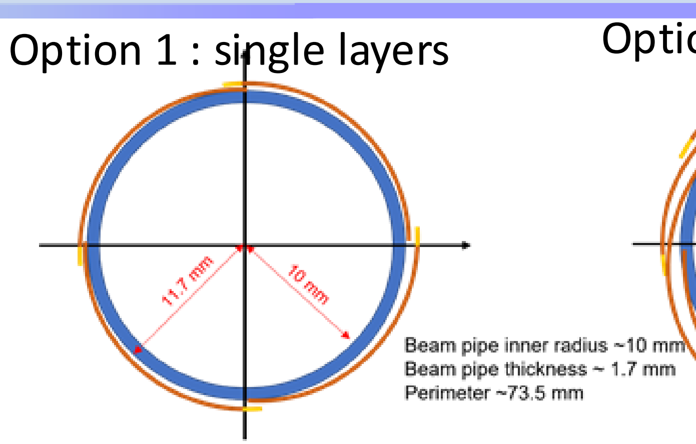
- Different steps :
  1. Chip demonstrator,
  2. Large chips for beam telescope application,
  3. Version targeting FCCee-like specifications.

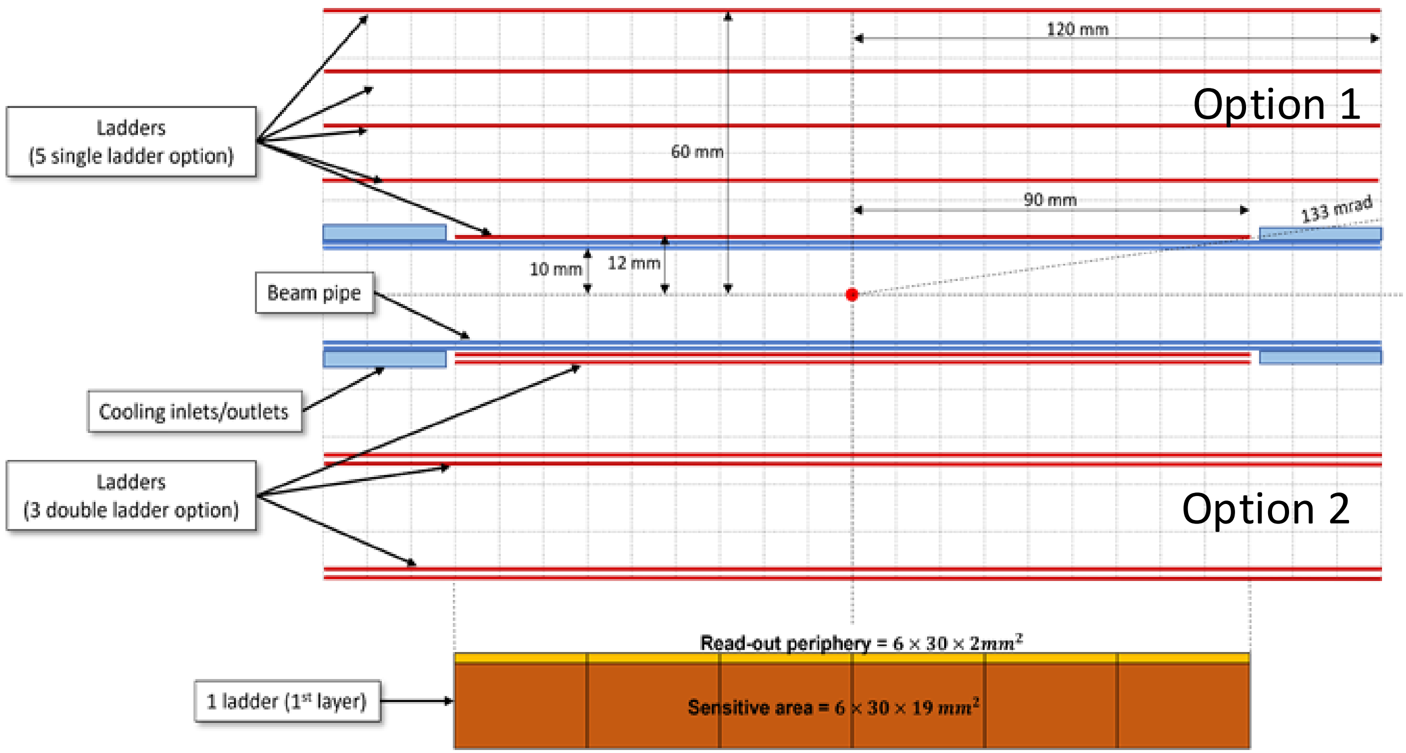
- No new chips to bend/tests until then => rely the one existing chips Mimosis (see later).

Fadoua Guezzi Messaoud, link1 link2



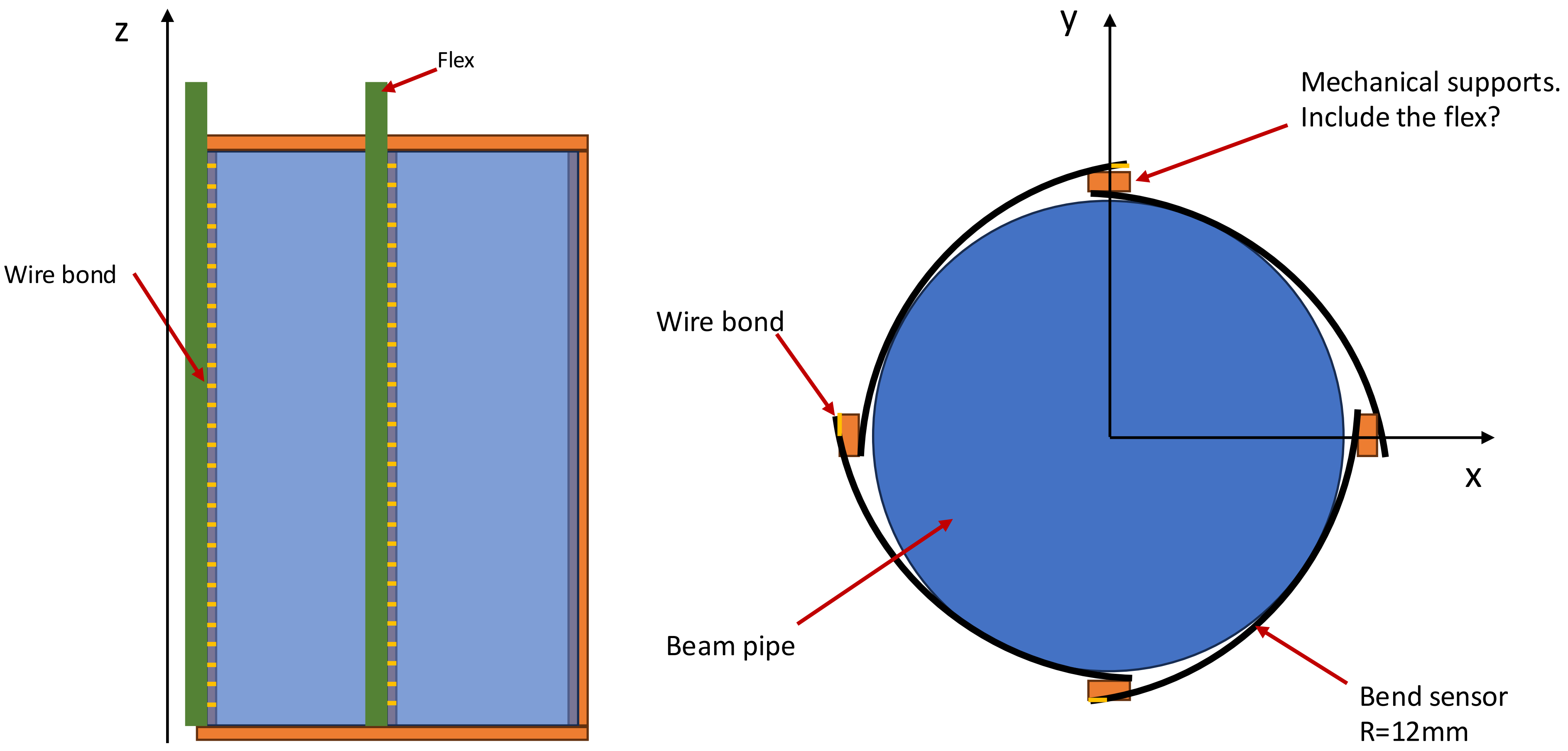
FCC-SEED : geometry concept





- Based on large size curved sensors (DRD8)
  - Smallest possible radius, first hits as close as possible to the collision point,
  - Minimization of the material budget.
- New geometry under study
  - Snail-like shape, slight sensor overlap,
  - Allow for a full r-phi coverage.
- Options to be explored :
  - Possibility of stitching,
  - Double sided vs single sided layers,
  - Layers radius and numbers,
  - Cooling options.
- **Coherent developments of sensors, mechanic, integration and simulation.**

FCC-SEED : geometry concept first thoughts



Wire bonding on the side

- Might make the stitching not needed,
- No dead region in phi,
- Makes the design of the mechanics and the flex quite challenging.

Assembly of quarters (hemi) of cylinders : assemble individual frames together around the beam pipe

FCC-SEED in full simulation

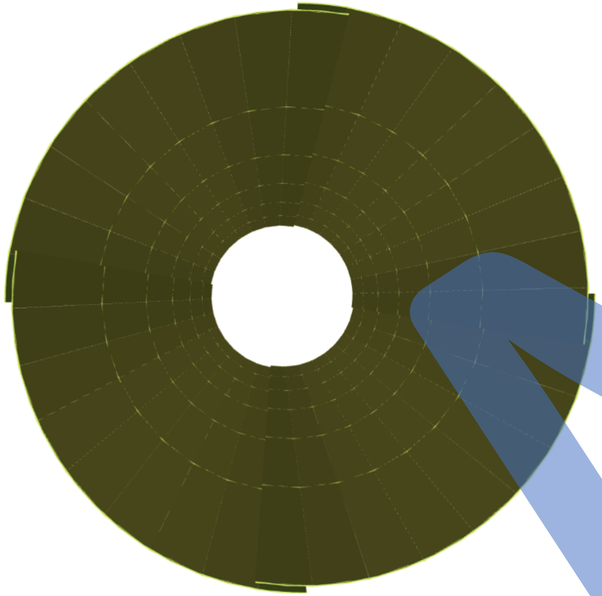
Armin Ilg, link

IDEA vertex/silicon wrapper geometry constructor can also represent FCC-SEED geometry!

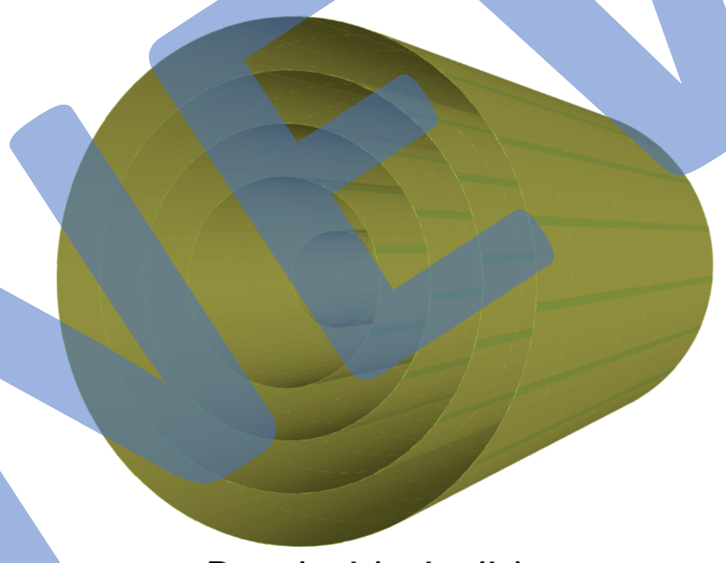
First implementation:

- Six barrel layers at $r = 12, 24, 36, 48, 60$ mm, single-hit layers
- No stitching in ϕ, width of $19 + 2$ mm (sensitive+periphery), overlapping in ϕ
- Stitching in z, length of stitched RSUs of $29.8 + 0.2$ mm (sensitive+periphery)

$\rightarrow$ Only 0.6% cracks in coverage (need to offset layers in z to avoid gap at $|\cos\theta| = 0$)



First layer



Barrel with six disks

Next steps:

- Add some simple disks (CLD-like)
- Add simple support structures
- Estimate performance using conformal tracking

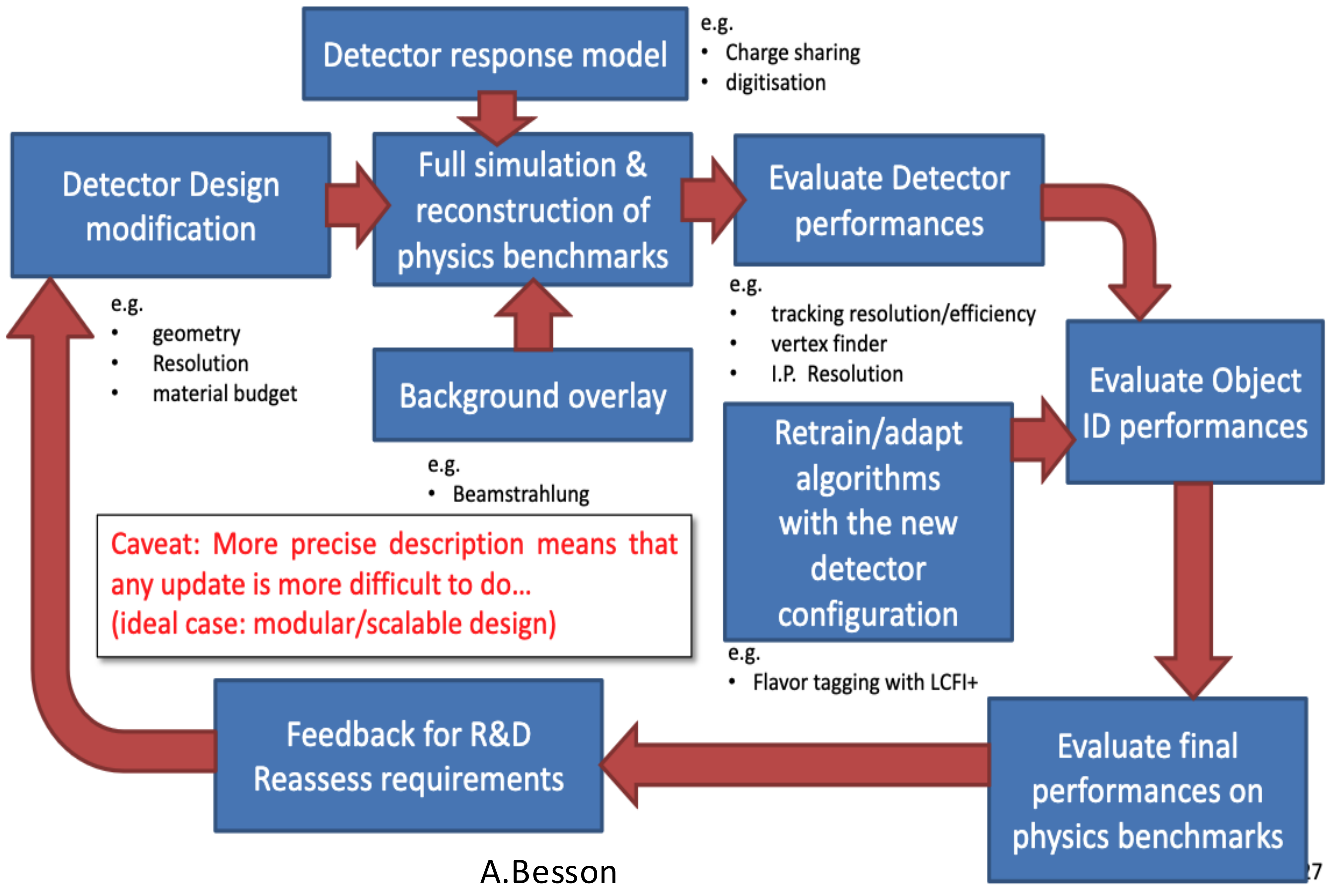
FCC-SEED : setting up the program

- Goals for mechanics and integration: work toward a robust vertex concepts for FCCee (or other e+e- colliders) in the coming ~5 years.

- Mains topics to worked on :
  - Master curved sensor fabrication and testing,
  - Explore mechanical options, type of material, stress and colling, etc…
  - Design a full mechanical geometry, to be tested in full simulation,

- Iterative process !

- Curved sensor, 3 steps identified :
  - **Step 1** : functional single curved Mimosis,
  - **Step 2** : "Super-Mimosis",
  - **Step 3** : demonstrator of a full layer 1.

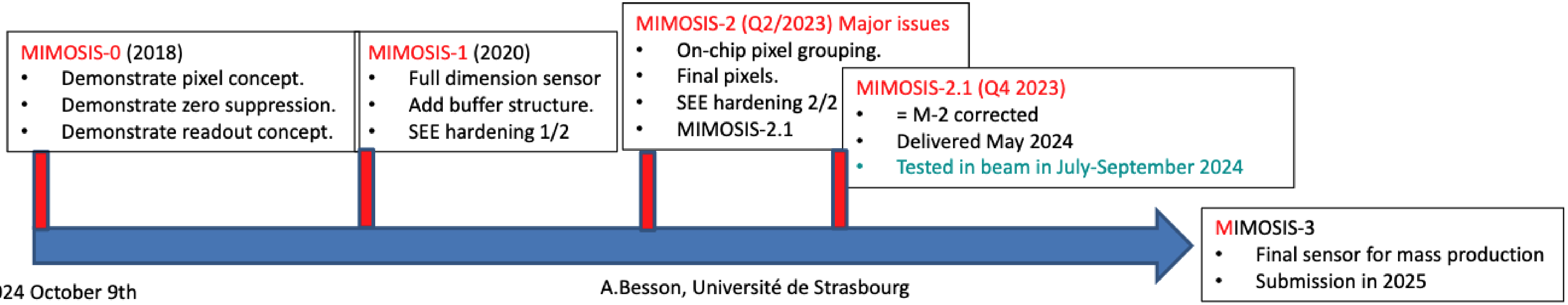


MIMOSIS

Physics parameter	Requirements
Spatial resolution	~ 5 um
Time resolution	~ 5 us
Material budget	0.05% X_0
Power consumption	< 100 – 200 mW/cm^2
Operation temperature	- 40 °C to 30 °C
Temp gradient on sensor	< 5K
Radiation tol* (non-ion)	~ 7 x 10^{13} n_{eq}/cm^2
Radiation tol* (ionizing)	~ 5 MRad
Data flow (peak hit rate)	@ 7 x 10^5 / (mm^{2}s) > 2 Gbit/s

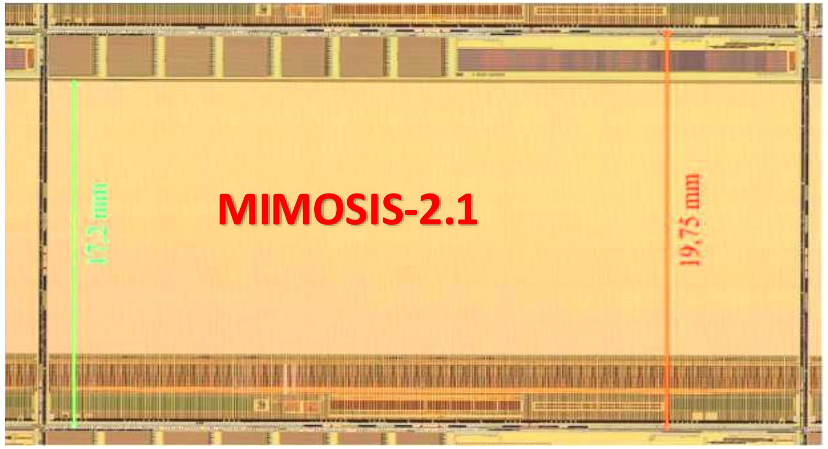
Parameter	Value
Technology	TowerJazz 180 nm
Epi layer	~ 25 µm
Epi layer resistivity	> $1k\Omega cm$
Sensor thickness	60 µm
Pixel size	26.88 µm × 30.24 µm
Matrix size	1024 × 504 (516096 pix)
Matrix area	≈ 4.2 cm^2
Matrix readout time	5 µs (event driven)
Power consumption	40-70 mW/cm^2

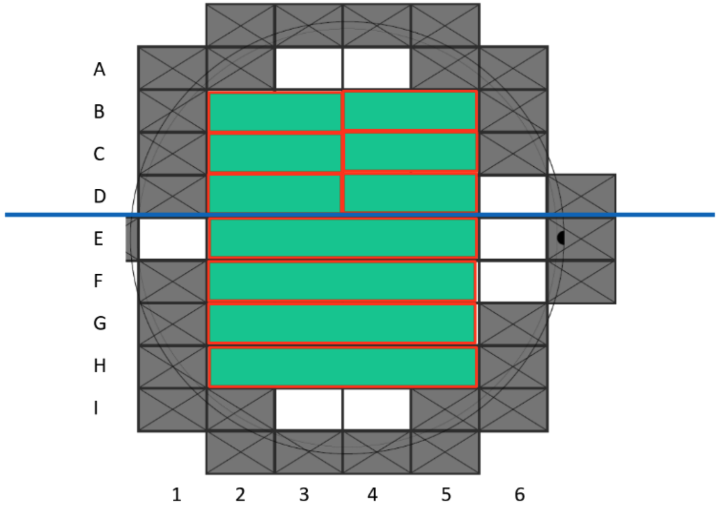
- Desiging of a new chip is a long process. To move forward, we are bending/testing already existing sensors : **MIMOSIS** (CBM experiment @ FAIR), IPHC (PICSEL, C4PI platform).
- MIMOSIS : based on Alpide architecture.
- Fulfil already a significant amount of specs : milestone toward e^+e^- colliders.
- Functional versions Mimosis 1 or 2.1 are good candidates for bend sensor testing.



Curved sensors

- Working plan :
  - Prepare and install sensor bending bench, with different radius options (12-15-18mm), and different sensor thicknesses (30-50 microns).
  - Practice bending with dummy sensors, then real functional single sensors (Mimosis), perform connectivity and setup DAQ, and tests.
  - Bending of a wafer slice (Mimosis), connectivity and tests,
  - Move toward a larger scale demonstrator of the 1st Layer in a few years from now.

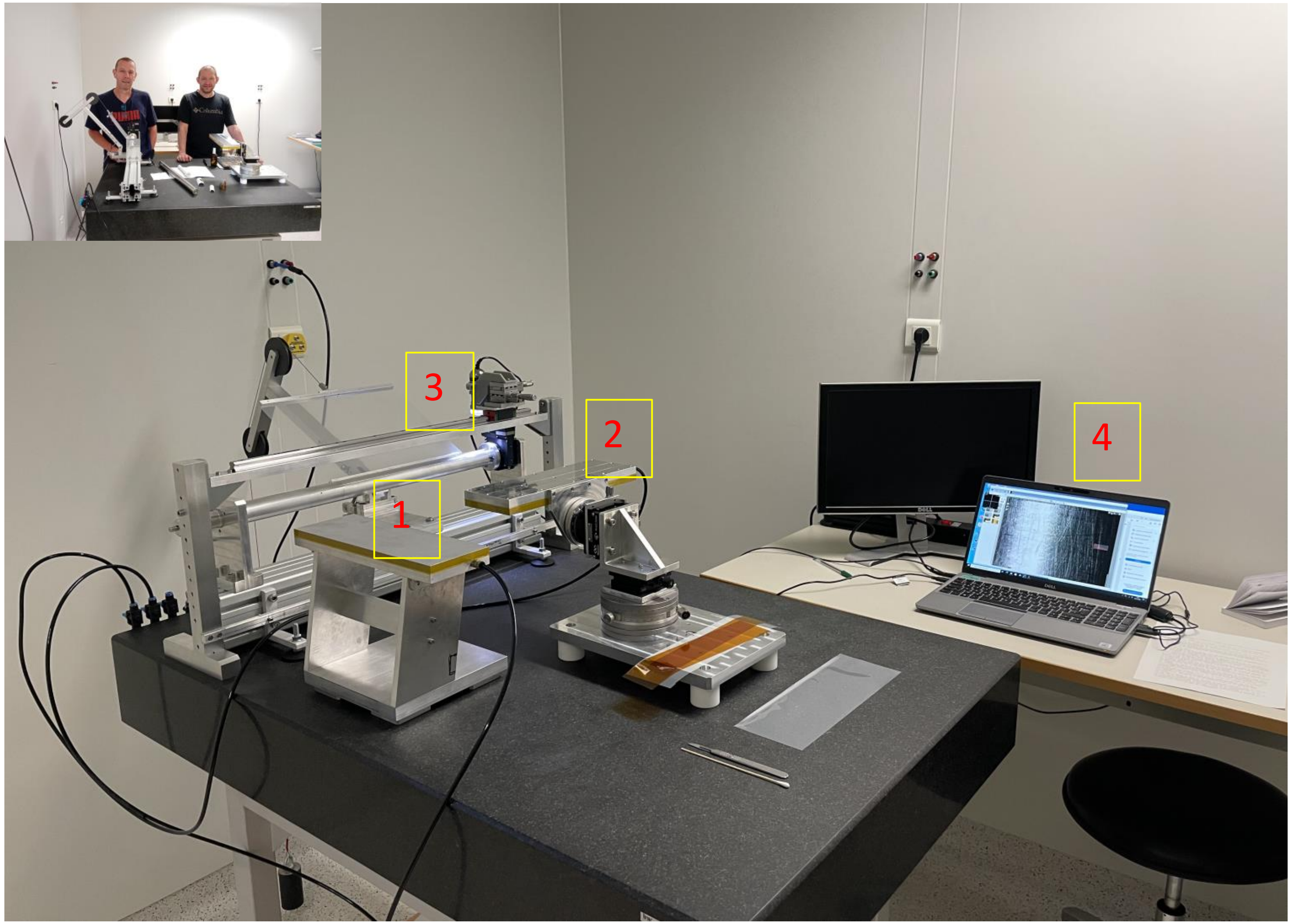




M.Goff

Bending bench – clean room setup

O.Clauss, F.Agnes



1. Fixed suction table,
   - preparation of the sensor,

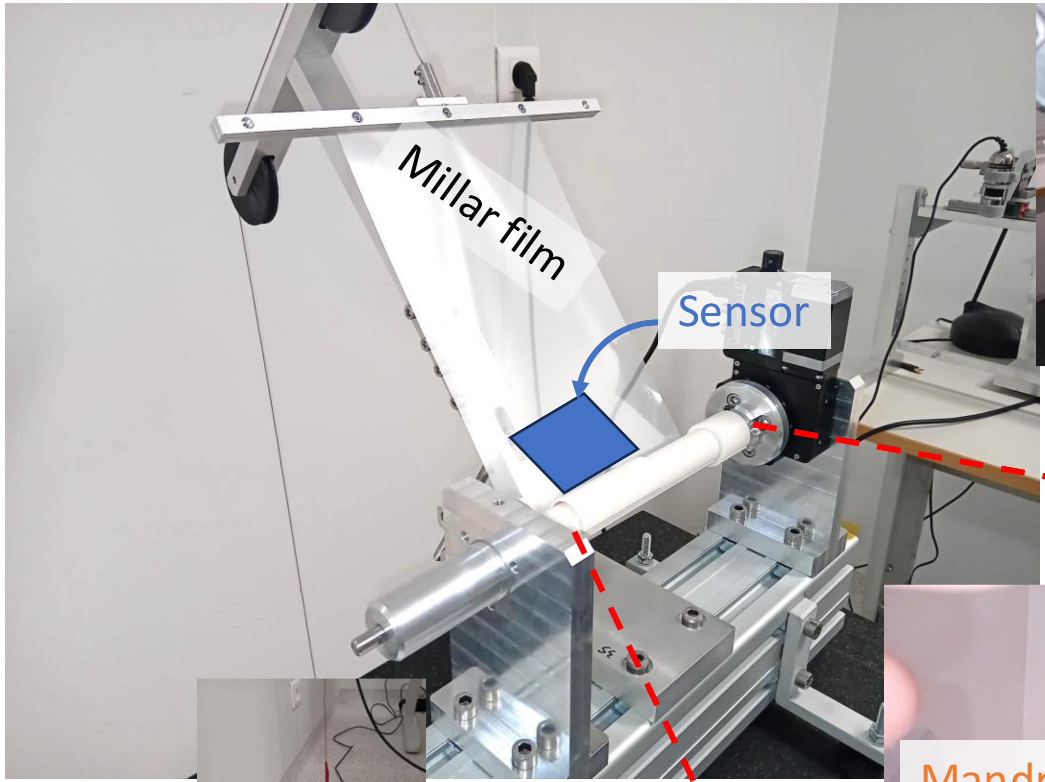
2. Mobile suction table,
   - Linear displacement in XYZ,

     Angular displacement in $\theta - \varphi$,
   - Pickup the sensor on 1, and precise positioning on the cylinder

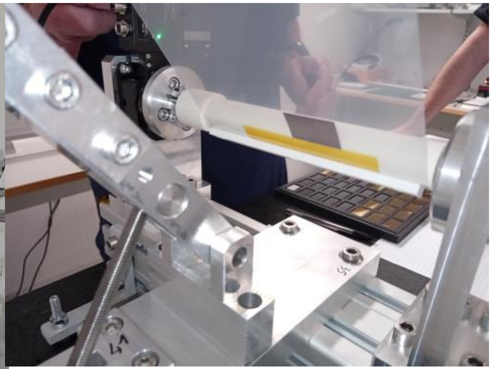
3. Bending of equipped silicon, motor for mandrel rotation, camera for alignment,

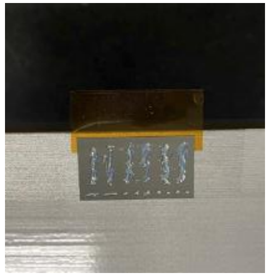
4. PC for camera display and other measurements.

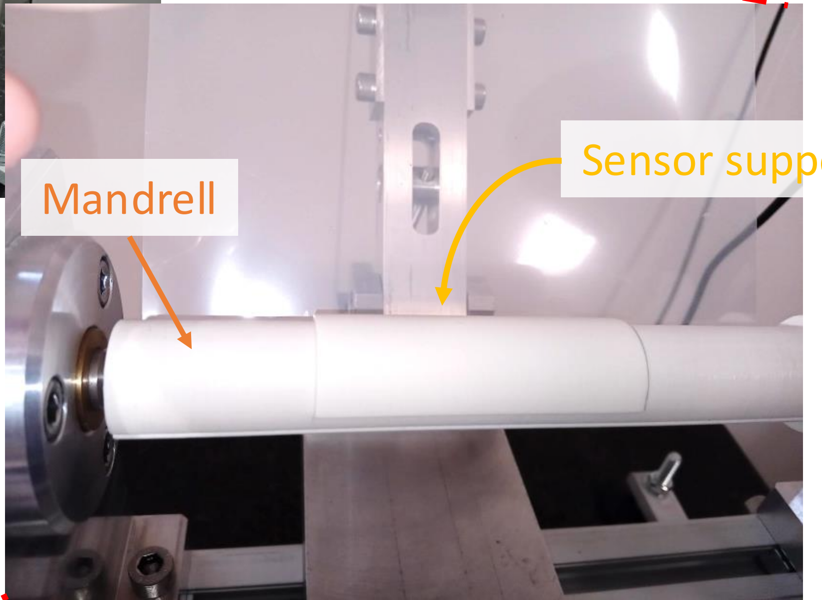
Sensor Bending

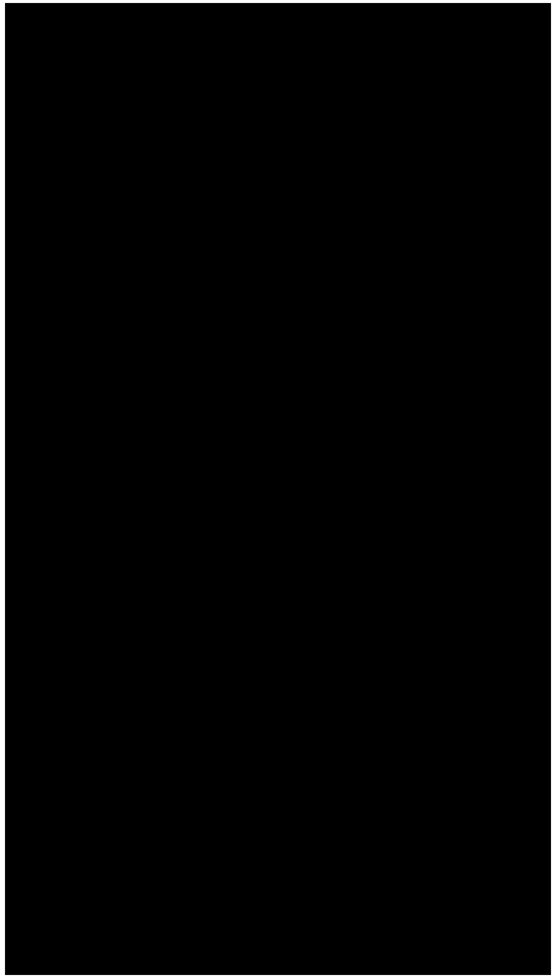


counterweight

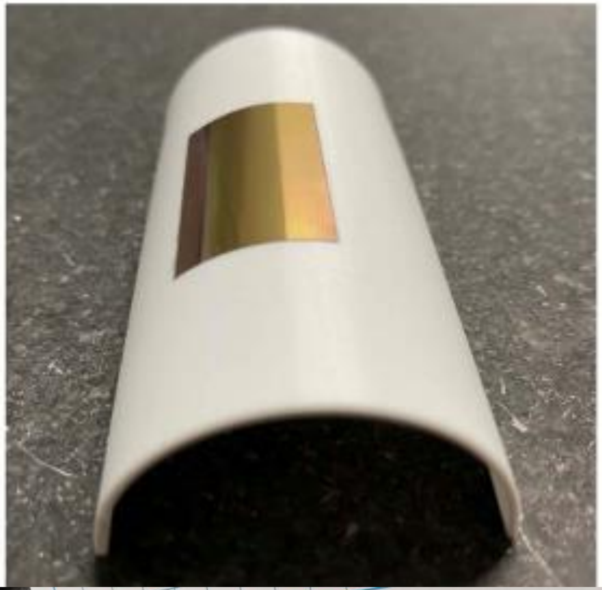




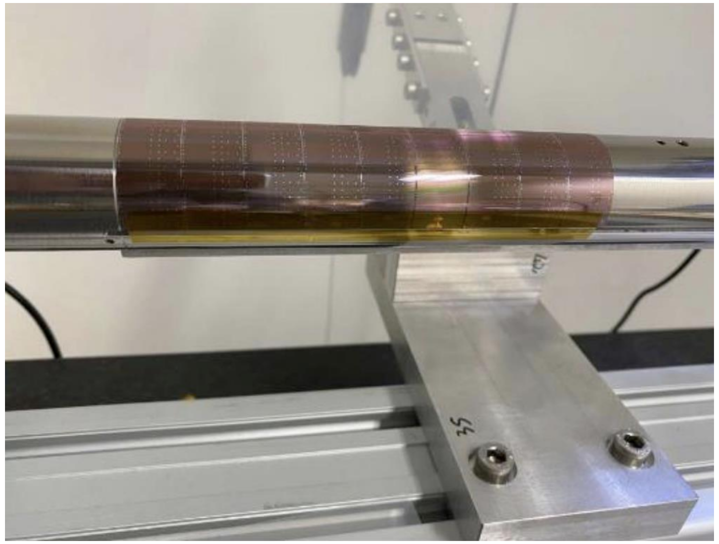




After bending



- Several tests performed, mainly on non-operational silicon pads or chips.
- Half-cylinder 3D printed supports placed on mandrel 3D printed => large flexibility for performing tests.
- Conclusion of the bending feasibility:
  - Large size silicon pieces bended successfully,
  - Bending at R=18mm successful with 50-60 microns thickness,
  - No issues observed with 3D printed cylinder and support.



- Further plan:
  - Tests bending at R=18, 15 and 12 mm,
  - With sensor thickness of 50, 40 and 30 microns (30 microns might not be feasible with Mimosis),
  - Move to metallic mandrel for the bending of final functional sensors.

Rolling leaf of glass **M.Krauth**

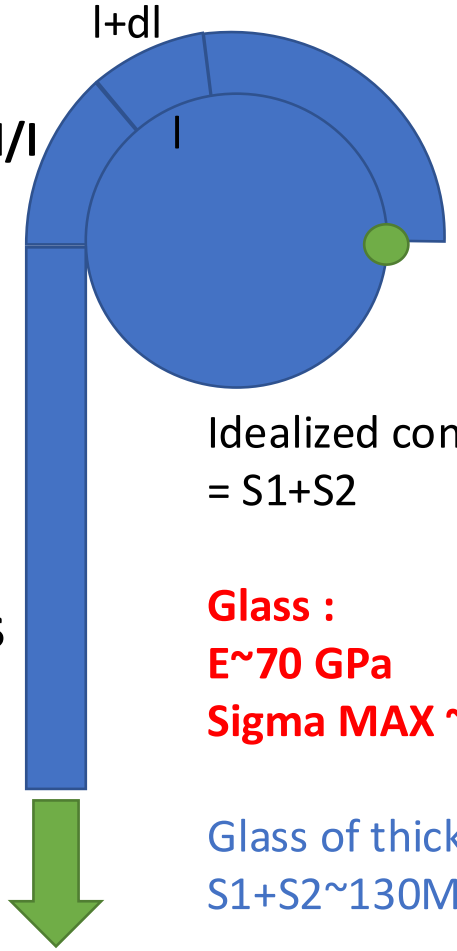
Simplified model

Rotative cylinder of diam. 36 mm

Maintained with a force of 50 N

S2 ~ E.dl/l

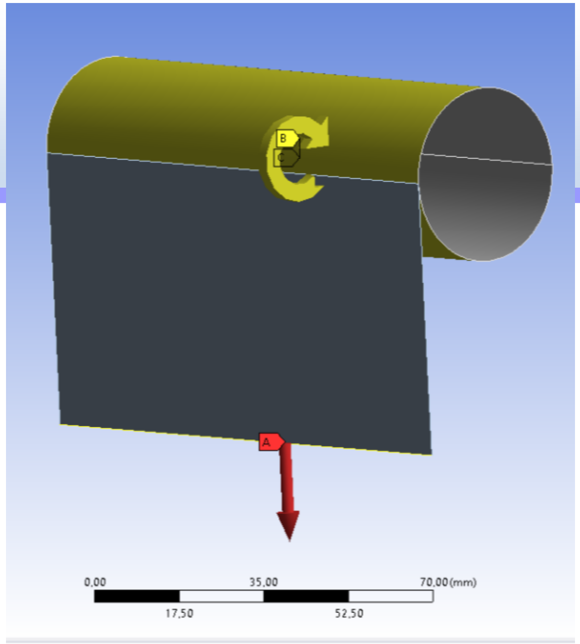
S1 ~ F/S



Idealized constrains
= S1+S2

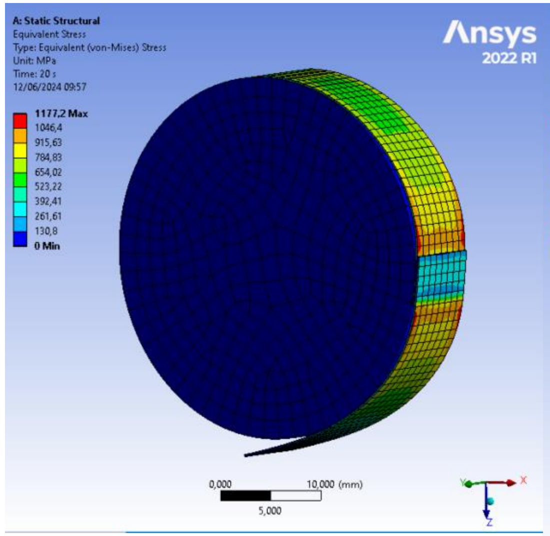
Glass :
E~70 GPa
Sigma MAX ~40à200MPa

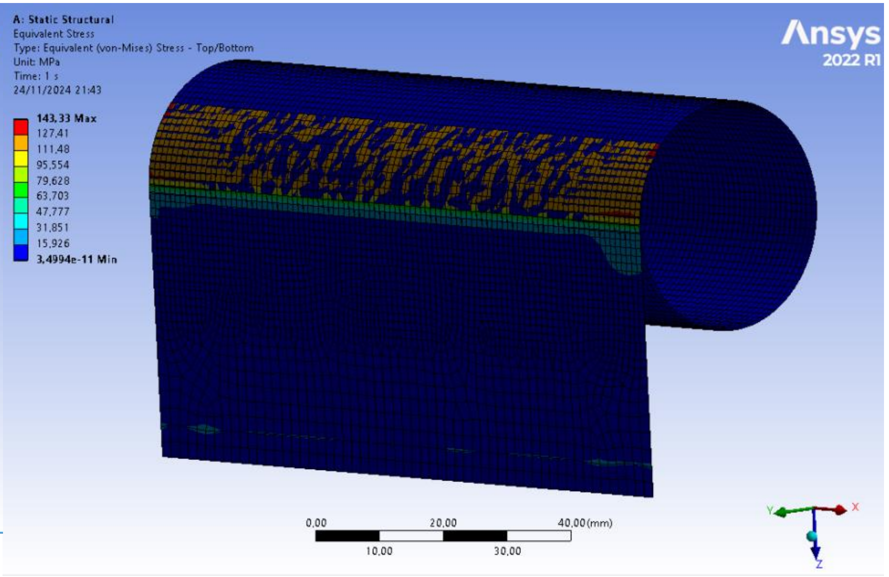
Glass of thickness of 30µm >>>
S1+S2~130MPa



ANSYS simulation

Glass thickness of 100 µm >>> 500 MPa
Glass thickness of 50µm >>> 200 MPa
Glass thickness of 30µm >>> 145 MPa





Mechanical characteristic of the sensor : mechanical tests ?

Preliminary mechanical studies, and to do

- Step 1 : study the physics performance with general geometry.

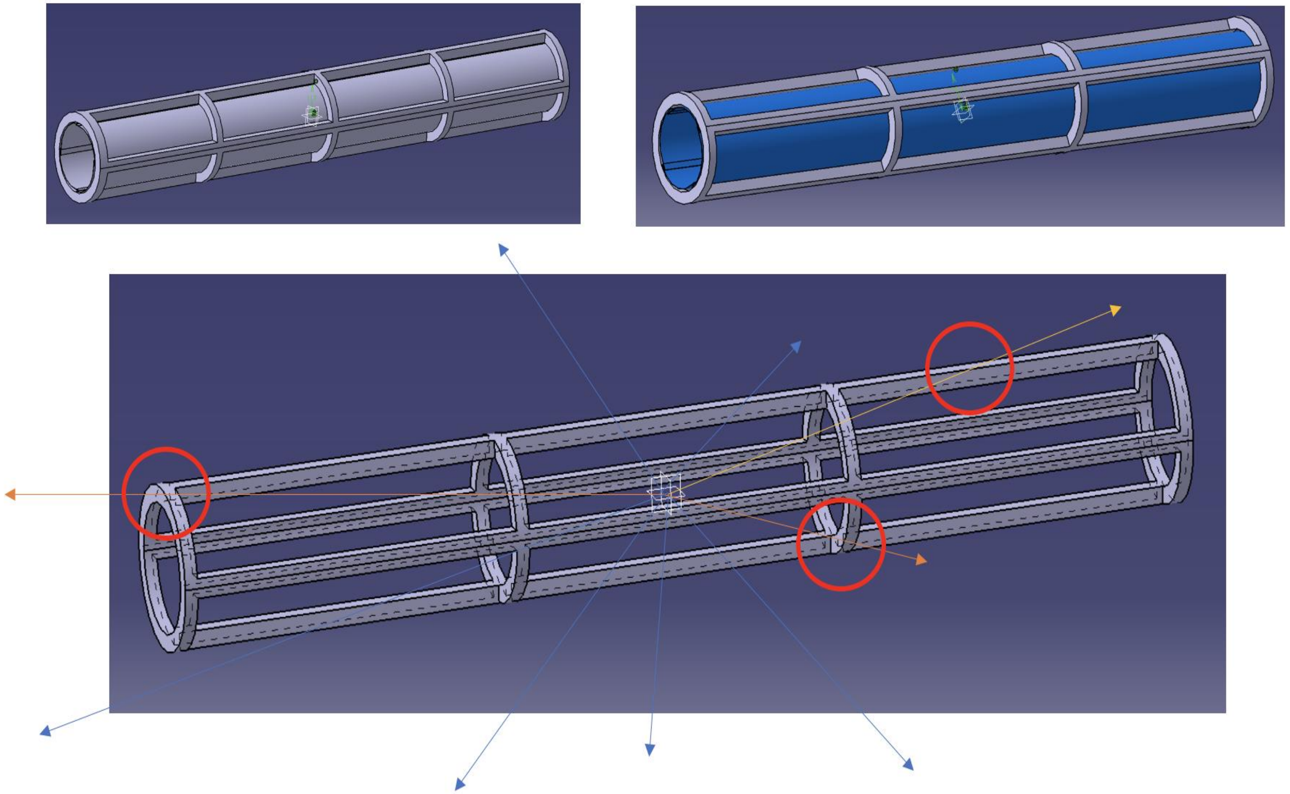
- Then several mechanical studies required
  - CAD implementation,
  - Simulation of mechanical and thermal deformations,
  - Thermal simulation for air cooling,
  - Choice and mechanical tests of material,
  - Study fabrication, mechanical assembly,
  - Supports for services.

- Very first example of design.

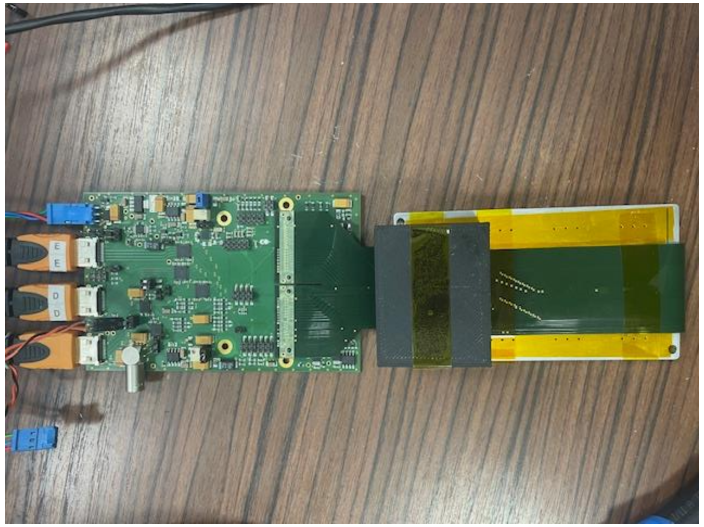
- Studies to be started sept 2025 (arrival of an apprentice engineer at IPHC).

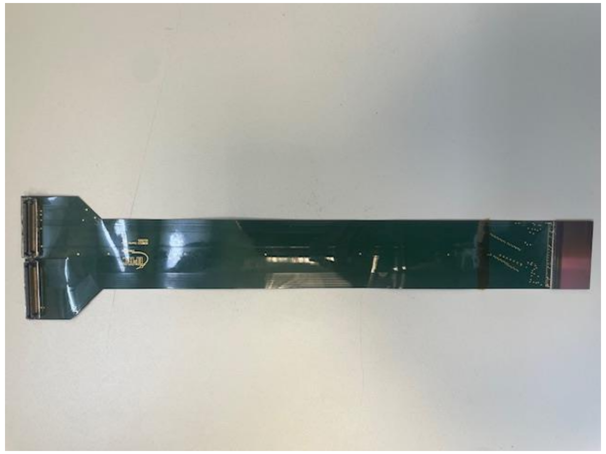
Longueur 240 mm, diamètre 33 mm
Impression 3D, polymère chargé carbone, renforcé en fibre continue (limite de faisabilité ???)

M.Krauth



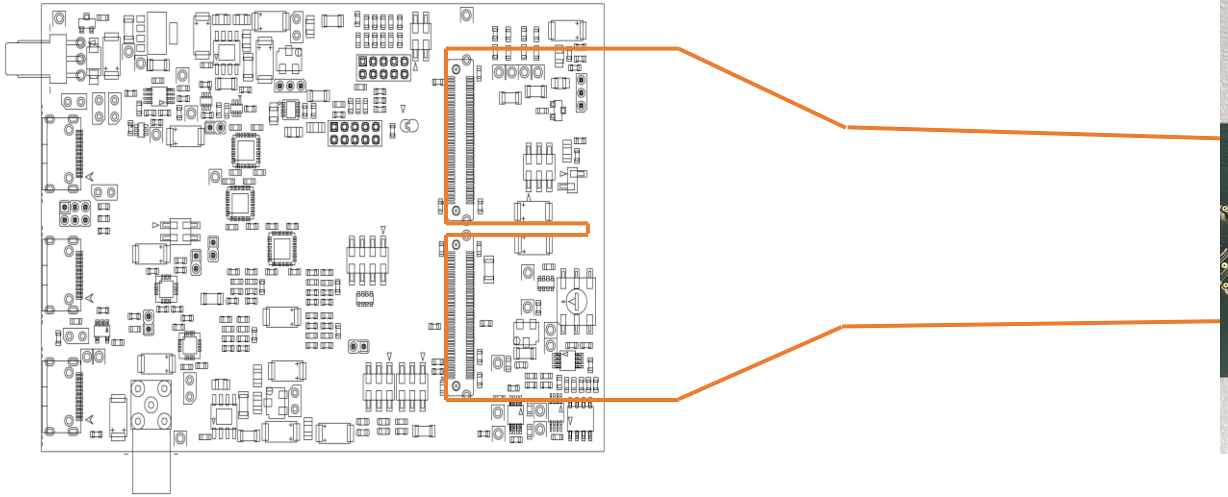
Design of a flex cable and board for curved mimosis testing

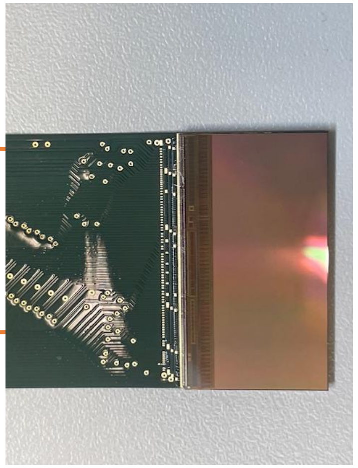




Carte Msis_prox

- Test board and flex for tests :
  - Design and fabrication done,
  - First tests performed mid-May/beginning of June,
  - Flex and board validated !
- First tests to be performed on MIMOSIS vs curved-MIMOSIS :
  - A/D power consumption,
  - Noise and s-curves,
  - Test with source and beam (CYRCé then DESY).





- For the final detector, the flex design is a key element.
  - Should allow for a robust and easy bonding,
  - Should be well integrated within the mechanics,
  - Should be as small and as light as possible.

JS Pelle, G.Claus, M.Goffe

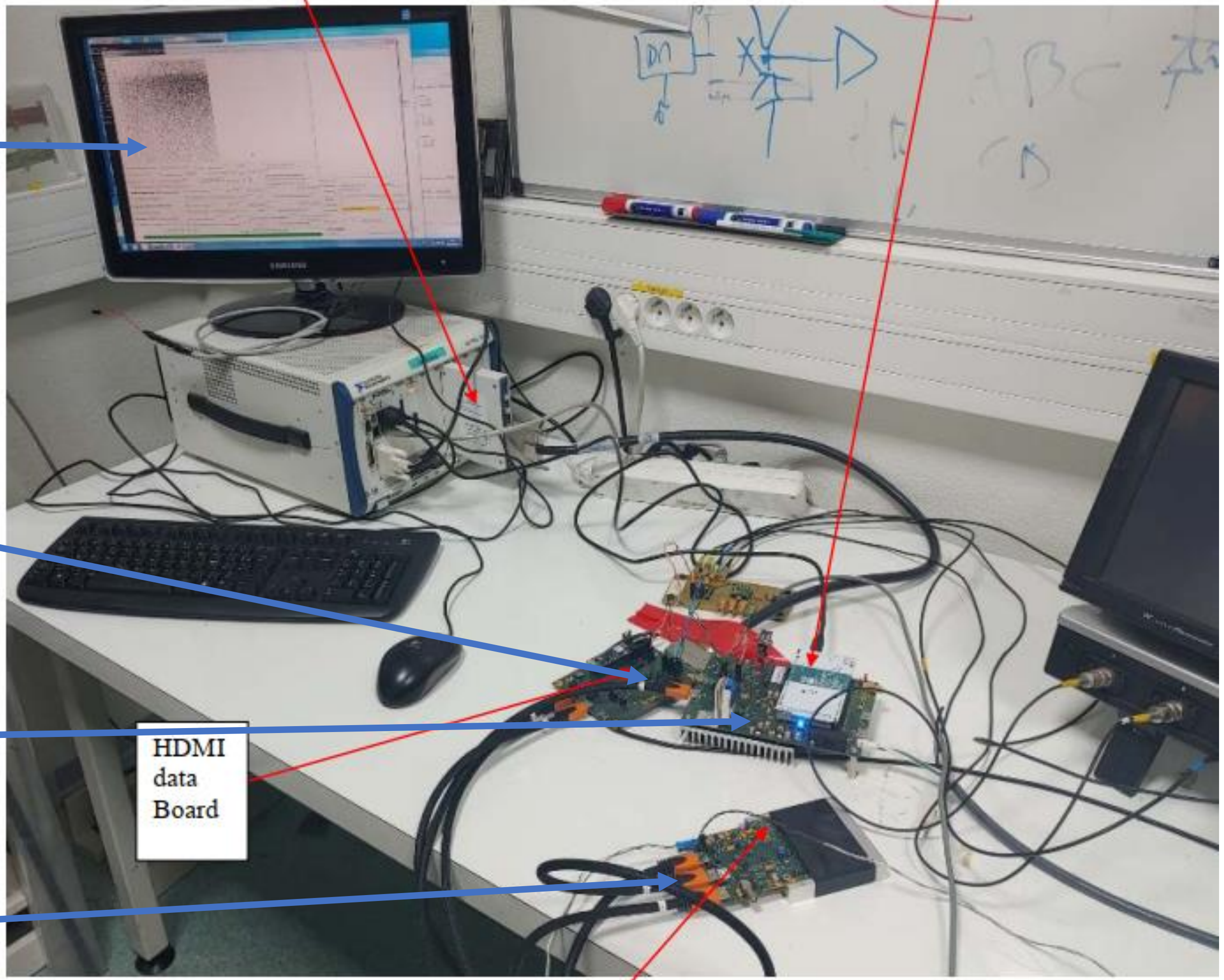
Test bench for Mimosis testing

- Le slow control & DAQ
  - NI PXIe crate
  - CPU + DAQ board FlexRio (FPGA)
  - SW tourney under Windows 7 Pro
  - DAQ : GUI executable (C++ Builder)
  - SC : GUI Python Q

DATA board transmission links to Mimosis / DAQ, 8 links at 320 Mb/s.

S3 board (Slow control Steering Synchro) provides slow control I2C and clock to Mimosis

Mimosis is mounted on a "Proximity board"

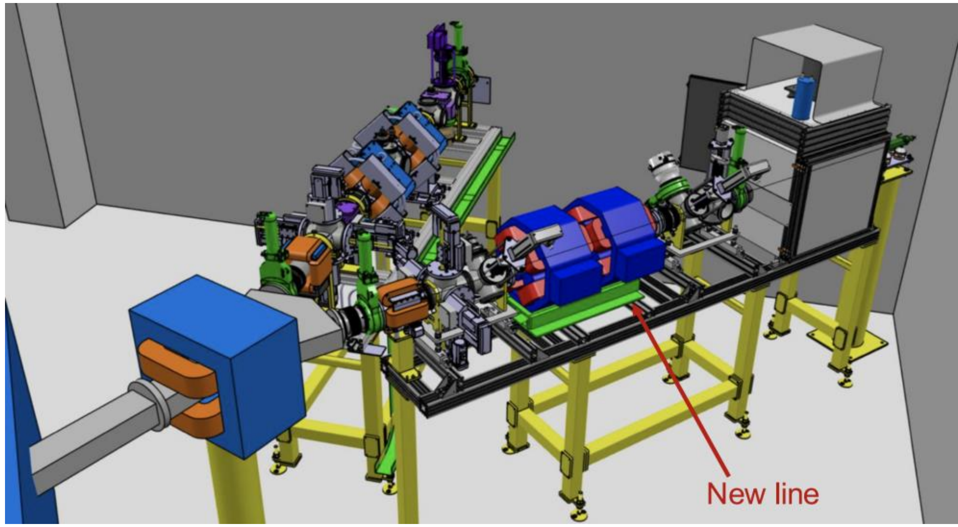


Possibility to have a DAQ based on cheaper FPGA under study. Software being made more user friendly

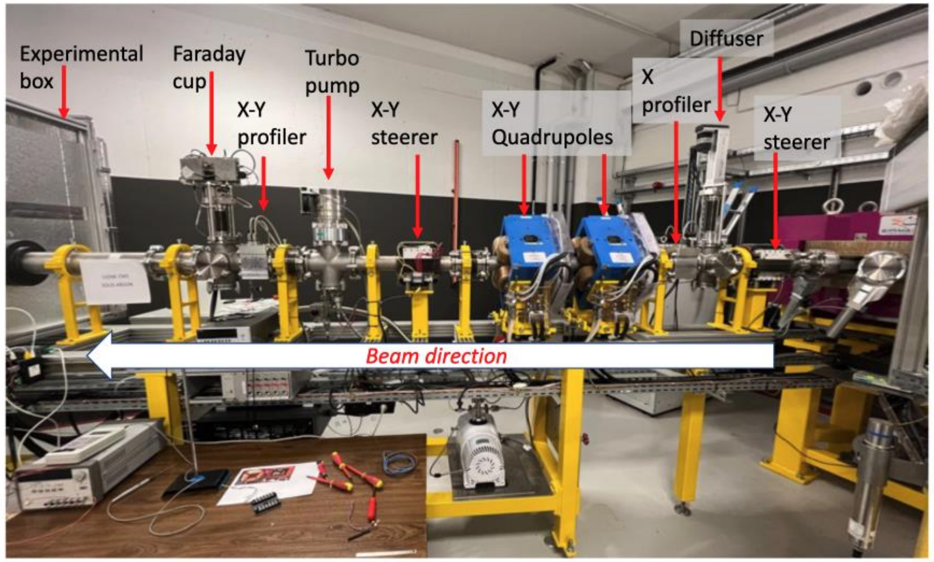
Beam test and irradiation facility : CYRCé@IPHC

- Cyclotron : initially meant for irradiation and production of radio nuclei.

- Beam characteristics :
  - **25 MeV Protons** (low energy, large energy deposition),
  - **Large intensities** : allows for irradiation
  - **Low intensities :** few fA ($\sim 6 \cdot 10^3$ protons per second), allows for test beam
  - **Beam structure** : bunches 85 MHz (~twice the LHC), which can be reduced to 42.5 MHz (kicker).



- Irradiation facility (in bunker):
  - Irradiation line installed and operational since July24,
  - Successful irradiation of CMS IT modules prototype (CROCv1) to 5x10^{15} neq/cm^2,
  - Irradiation time of 1.5 hours.



- Test facility (in exp. area):
  - Operational since 2020,
  - Well suited for rate studies and efficiencies measurements,
  - Limited precision due to multiple-scattering.

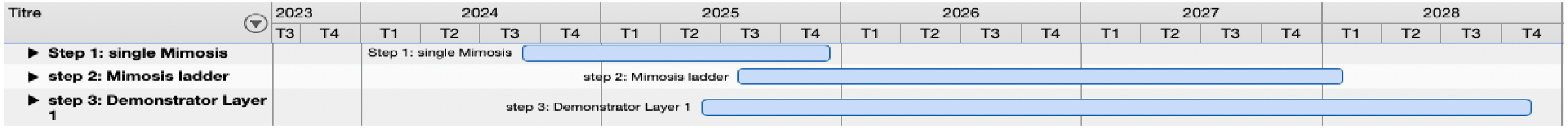
Outlook and next steps

- Single curved Mimosis well advanced. Beam test schedule at DESY for the end of 2025.

- But a lot remains to be done :
  - Chip R&D as part of DRD3,
  - Tests and optimisation of the geometry with Full Simulation,
  - Mechanical designs,
  - Electronics and flex designs,
  - Cooling !
  - Etc… etc…

- Three steps plan:
  - Single Mimosis curved => gaining expertise, characterise the curved sensor performance,
  - Curved Mimosis ladder => first design of mechanics, and integration plan,
  - Demonstrator of an entire curved Layer 1 => toward more final designs,
  - In parallel, long term activities required on full-simulation, impact on physics benchmark analysis.

- **Program made possible thanks to the C4PI platform !**



Long road ahead…

- FCC-SEED is a new (and young) vertex concept for FCCee :
  - based on curved sensor and original design, thanks to chip design and integration choices,
  - plan to study coherently chip designs, mechanics, cooling and integration,
  - generic : can be ported/adapted to any detector concepts,
  - collaboration to be extended abroad.

- While dedicated chip designs happens, use existing chips (Mimosis) for mechanical and integration studies.

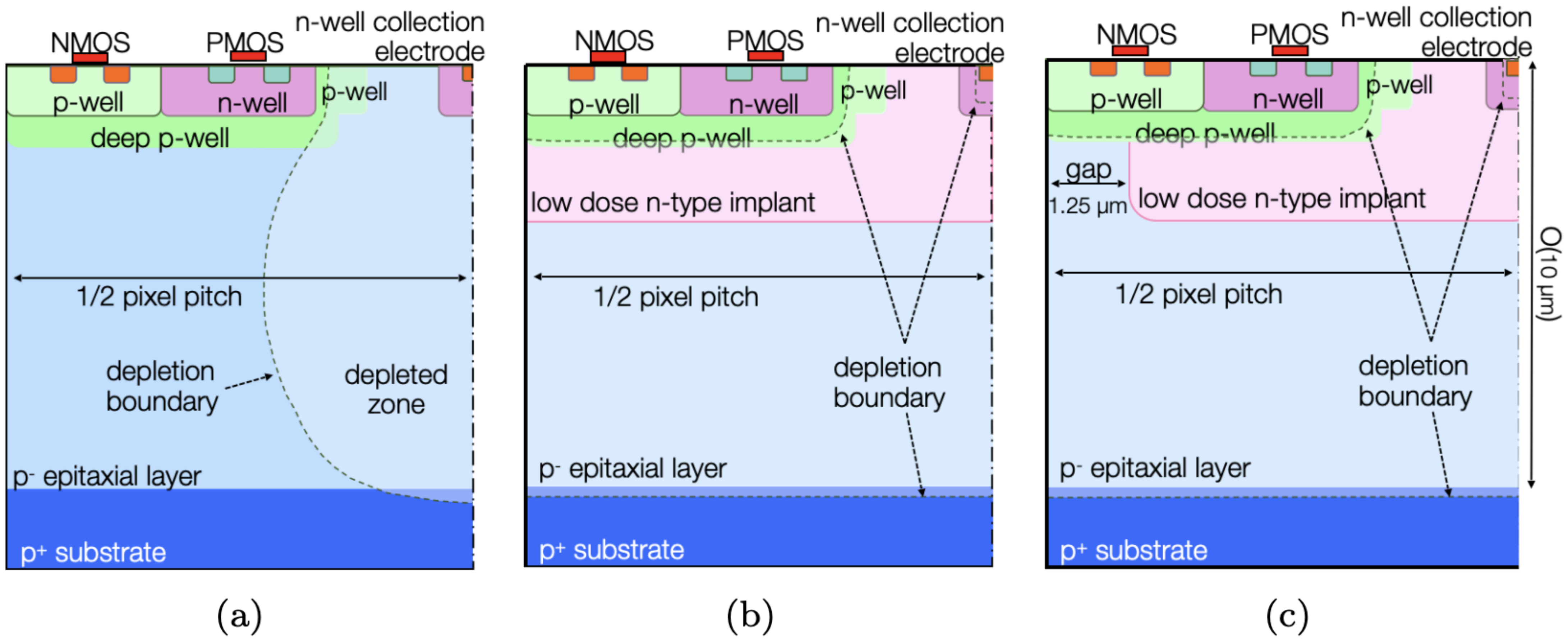
- So far, six in2p3 laboratories shown interests, the activities are (slowly) ramping up.
  - FCCee start targeted to ~2040,
  - Specific R&D and construction usually takes ~10 years,
  - => we have ~5 years to make preliminary feasibility studies, and have a more mature project.

Backups

Task diagram

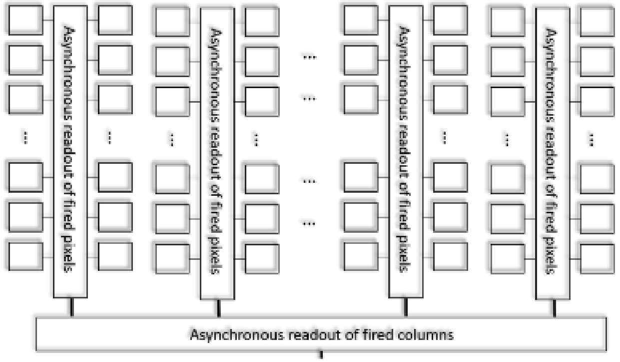
- **Curved Mimosis**
  - **Bending**
    - Design of the bending setup
      - Overall concept
      - Drawings
      - Documenting bending procedure
    - Fabrication and usage of the bending setup
      - Production and quality control of 3D printed plastic mandrel
        - Produce mandrels with radius of 12, 15 and 18 (mechanical tests)
        - Produce mandrels with radius of 11, 14 and 17 (functionall tests)
        - metrology
        - Surface finish
      - Bending on a 3D printed cylinders
        - Mechanical tests for different diameter and different detector thickness
        - Functional Mimosis : tests for different diameter and different detector thickness
      - Production and quality control of metallic mandrels
        - Production
        - metrology
        - surface finish
  - **Mechanic**
    - Mechanical simulation
      - Simulation of silicone mechanical deformation
    - Support design and fabrication
      - Design of hemi-cylinder shell, with opening for tests with particle, with different radius (12, 15, 18) and 1mm width
      - Fabrication and validation of the supports
  - **Sensors production**
    - Cut non functional Mimosis and different width, for bending testing : 30, 40 and 50 microns
    - Cut functional Mimosis with width of 30, 40 and 50 microns
  - **Integration**
    - Design of Flex
    - Fabrication of Flex
    - Flex gluing
    - sensor installation and gluing
    - wire bonding
    - Fan cooling
  - **Testing**
    - Design and installation of test setup
      - Develop FPGA-based DAQ
      - Cooling and temperature monitoring
      - Deploy DAQ system in different labs
    - Mimosis Irradiation
      - Determine fluence
      - Irradiate sensors
      - Test irradiated sensors
    - Test data taking
      - Determine test to be done without particles
      - Take data without particles
      - Determine tests to b done with particles
      - Take data with particles
      - Interpretation

Bent sensor project part of GRAMM MP and DRD8

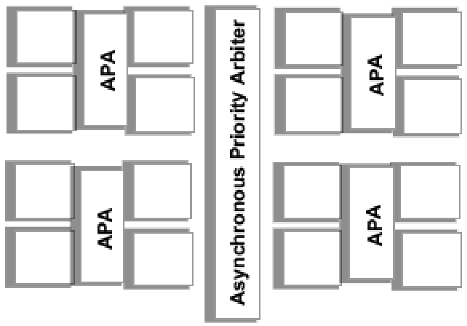

NMOS
PMOS
n-well collection electrode
p-well
n-well
p-well
deep p-well
low dose n-type implant
gap
1.25 μm
1/2 pixel pitch
depletion boundary
depleted zone
p- epitaxial layer
p+ substrate
O(10 μm)
(a)
(b)
(c)

Architectural Options

1 readout logic / double-column (~ALPIDE/MOSAIX)



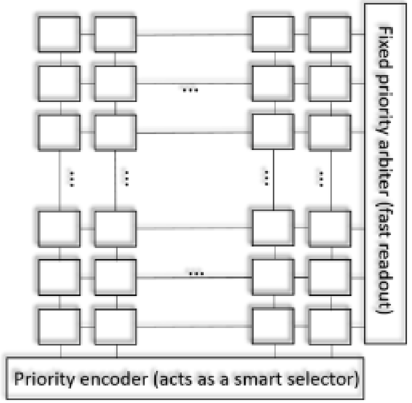
Pixel-grouping readout logic



* APA: Asynchronous Priority Arbiter

Temporal resolution ? Power?

1+1 readout logic / matrix (~MOSS)



Larger pitch → **Smaller pitch**

Higher hit rate ← **Lower hit rate**

- New FE: 2 thresholds / pixel
  + Charge sharing

❌ **Not sure to achieve fine pitch**

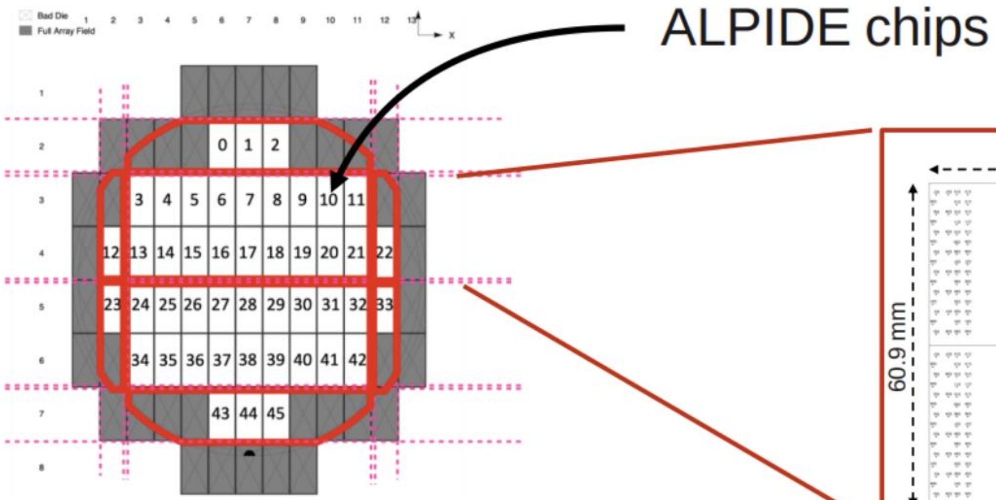
- DPTS pitch: 15 µm
- ToT measure

✔ **More realistic and secure**

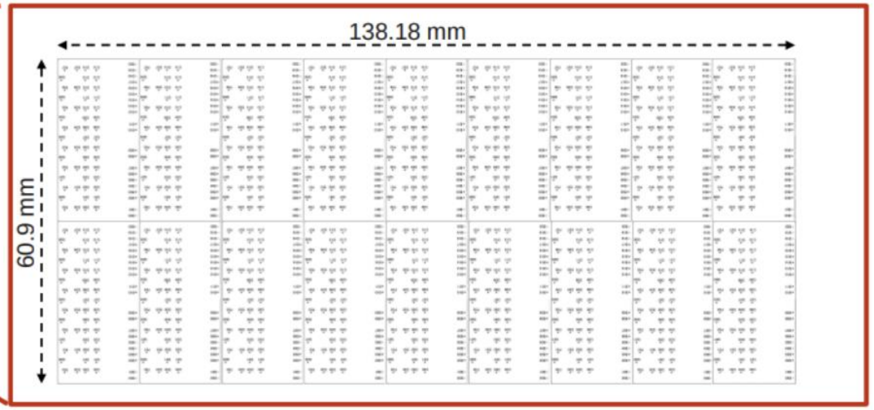
- Possible pitch down to 15 µm (APTS)

❌ **Possible large dead area (large digital column) + low hit rate + no possible further improvements**

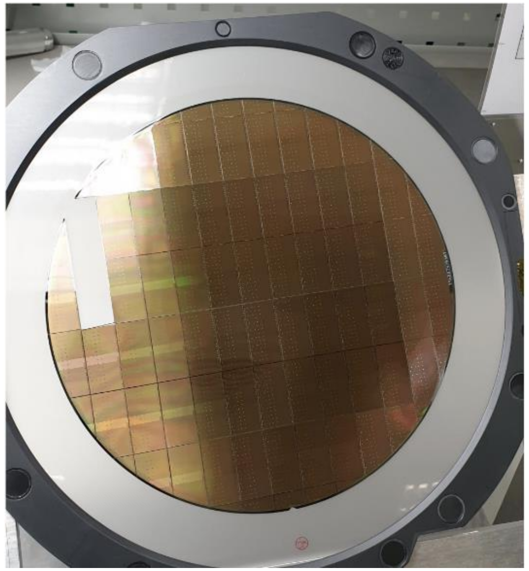
Super Alpide



Alperen Yuncu, link



18 ALPIDE chips, covering about a half of an ITS3 half-Layer0



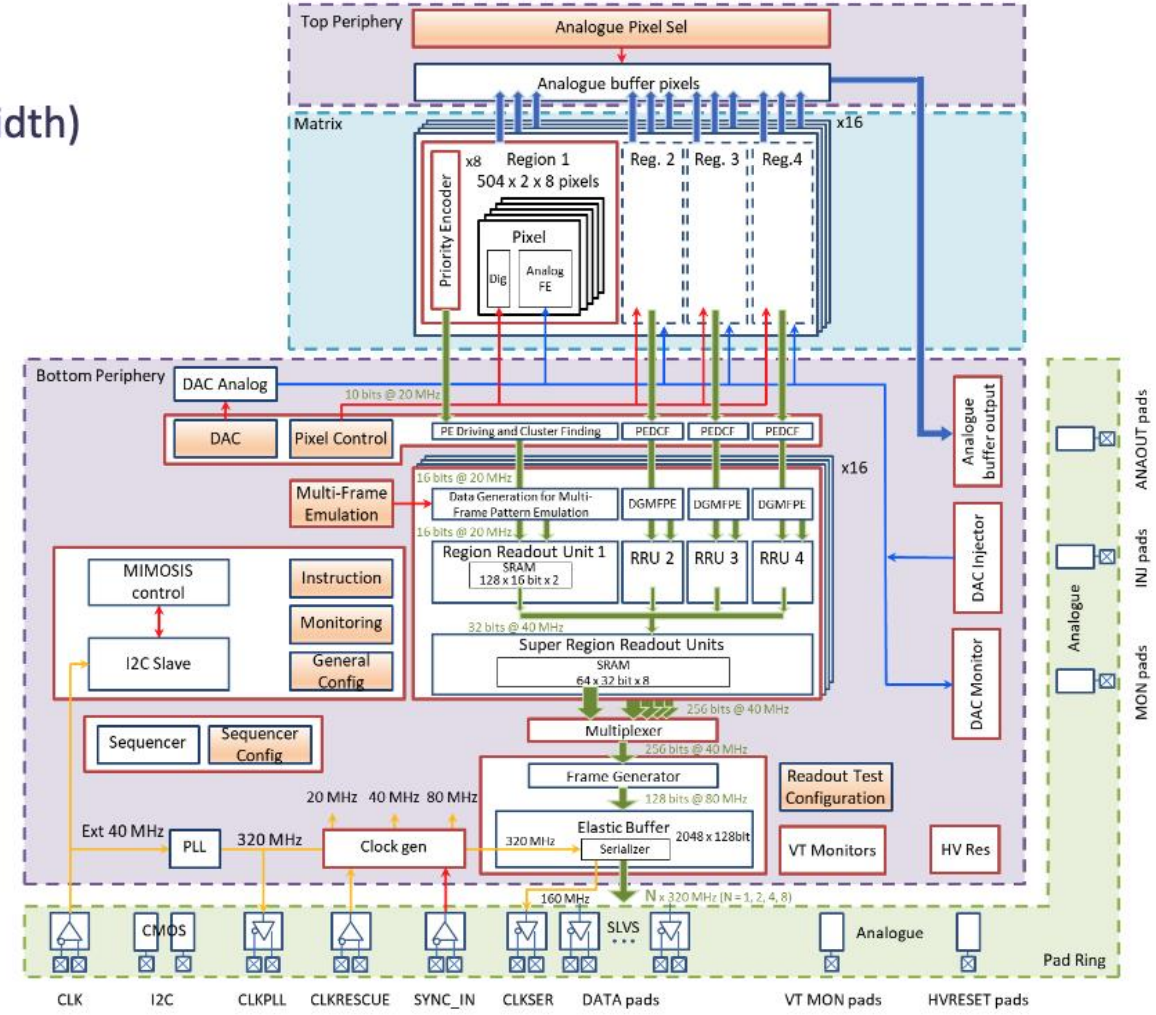
- Super-ALPIDEs are actually an array of ALPIDES.
- They consist 9×2 ALPIDE chips.

Mimosis

F.Morel, link

MIMOSIS diagram

- Matrix dimension: 1024 col. X 504 row
- Pixel dimension: 26.88 µm (height) x 30.24 µm (width)
- Integration time: 5 µs
- Tower Semiconductor 180 nm
- 4 sub-arrays for threshold adjustment
- 3 steps prototyping:
  - MIMOSIS0 small scale prototype (2017)
  - MIMOSIS1 first full scale prototype (2020)
  - MIMOSIS2 final prototype (2021)
  - MIMOSIS3 pre-production run (>2022)



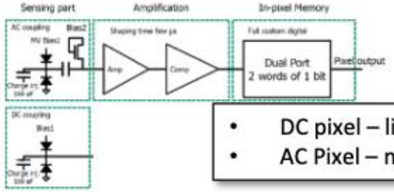
A.Besson, ECFA Paris 2024

DESY & CERN test beam

MIMOSIS-2.1: excellent performances

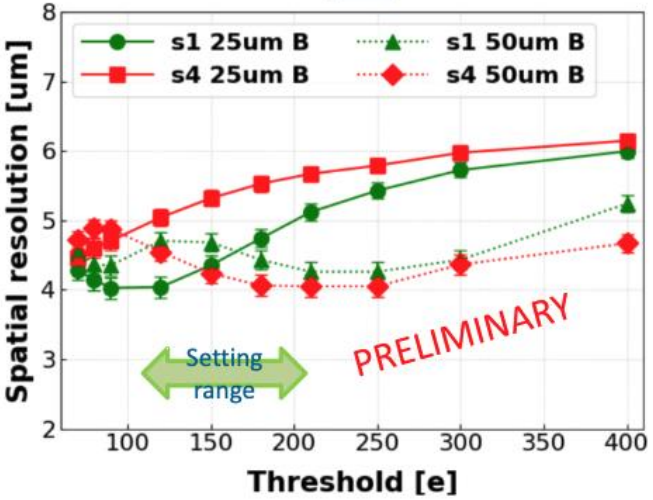
First proposed by W. Snoeys et al.
H. Pernegger et al., 2017 JINST 12 P06008

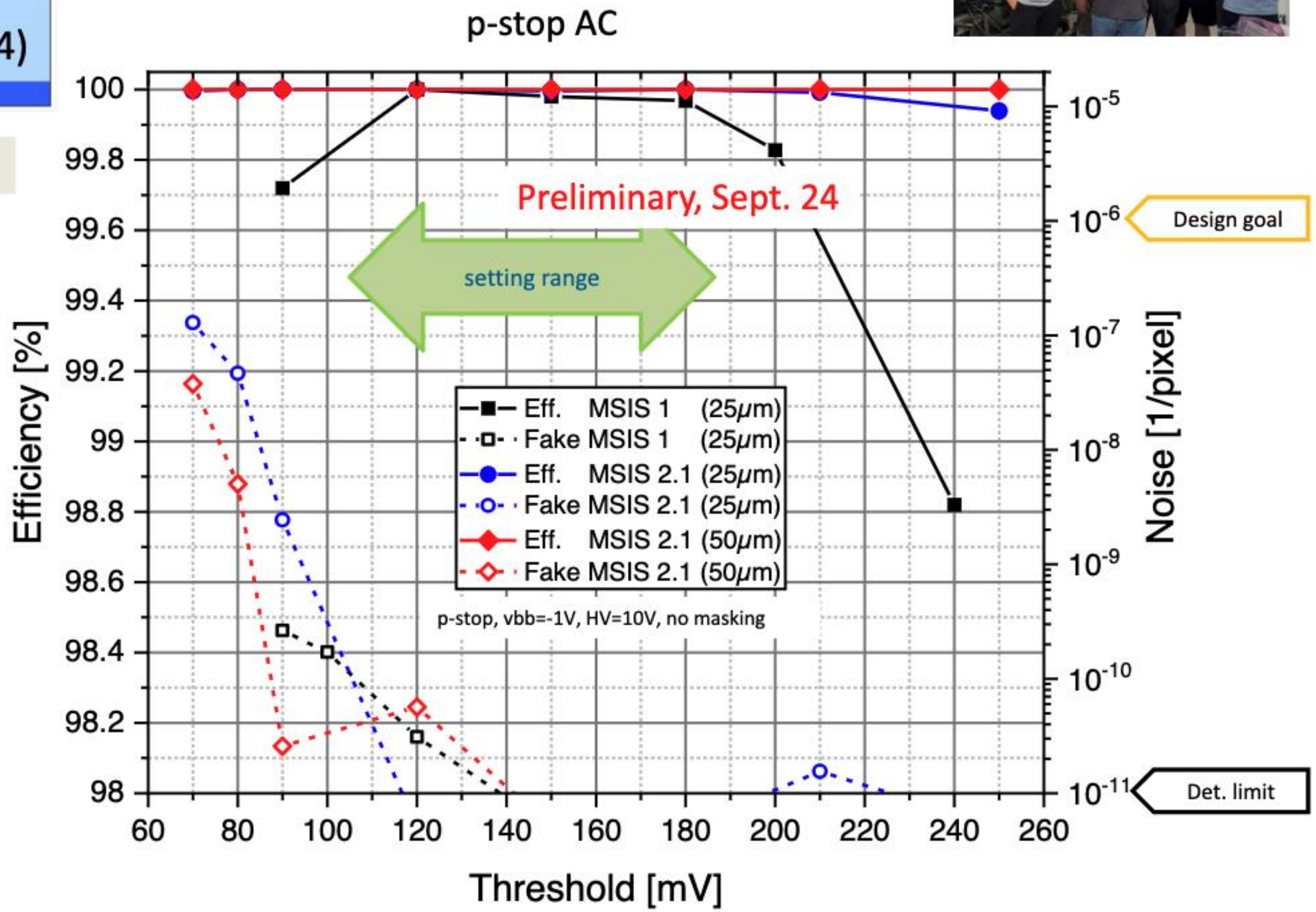
MIMOSIS-2.1: 25µm OR 50µm epitaxial layer



- DC pixel – limited rad. hardness.
- AC Pixel – more biasing lines.

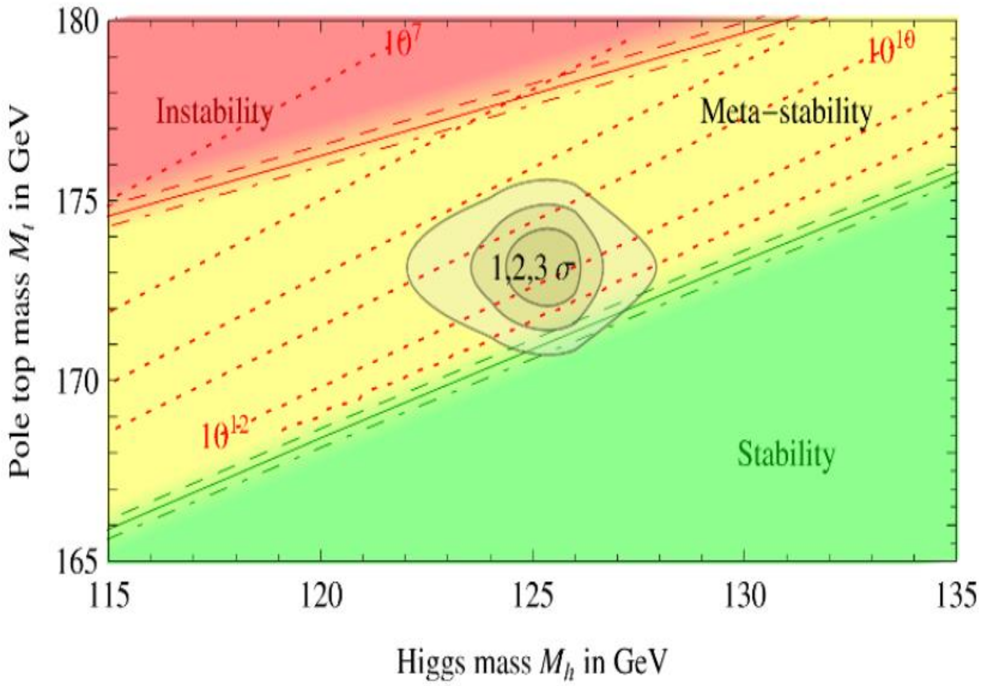
AC





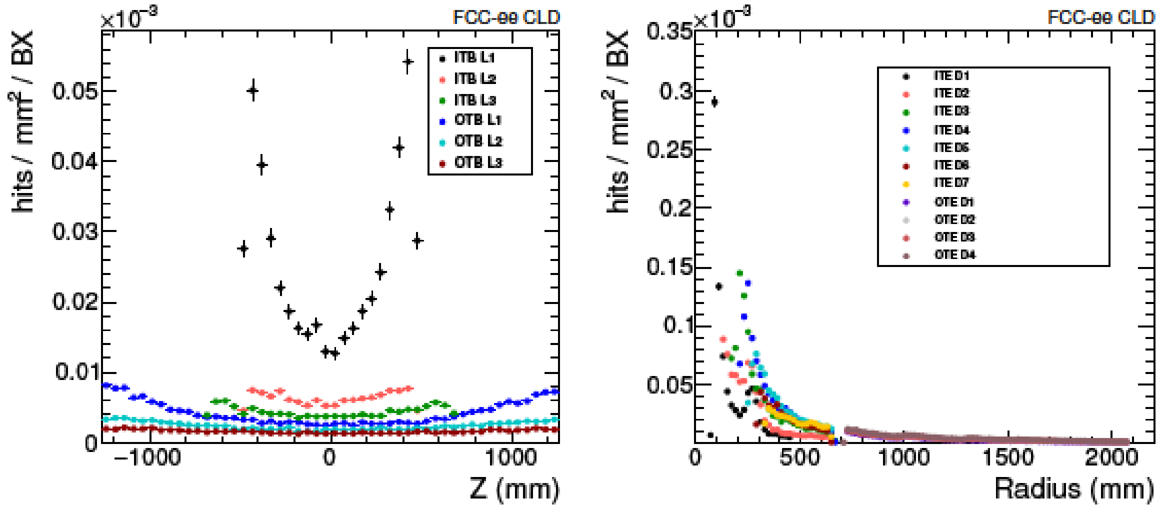
Top mass : target

JHEP08 98 (2012)



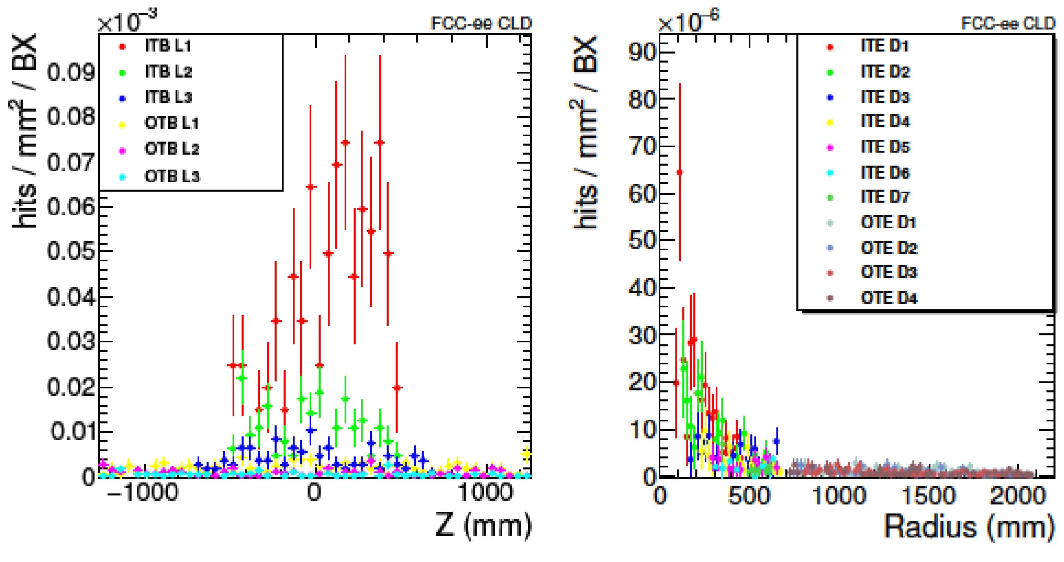
- Objectives of top mass measurement :
  - Test of the SM, yukawa couplings and top mass,
  - Confront pole mass to the "MC" mass (differences of a coupe f hundreds MeV),
  - Study of the stability of the vacuum, differentiations between stable and meta-stable universe.

Beam background



(a) (b)

Figure 17: Hit densities in the CLD tracking detector barrel layers (a) and discs (b) for particles originating from incoherent pairs, for operation at 365 GeV. Vertical error bars show the statistical uncertainty, horizontal bars indicate the bin size. Safety factors for the simulation uncertainties are not included.



(a) (b)

Figure 18: As Figure 17 but for hits related to synchrotron radiation photons.

Breit-Wheeler

$$\gamma + \gamma \rightarrow e^- + e^+$$

Bethe-Heitler

$$\gamma + e^\pm \rightarrow e^\pm + e^- + e^+$$

Landau-Lifshitz

$$e + e \rightarrow e + e + e^- + e^+$$

Bremsstrahlung

$$e + e \rightarrow e + e + \gamma$$

$\sqrt{s}$ (GeV)	91.2	365
Total particles	800	6200
Total E (GeV)	500	9250
Particles with $p_T \geq 5\,\mathrm{MeV}$ and $\theta \geq 8^\circ$	6	290

Rates of electron pair backgruonds

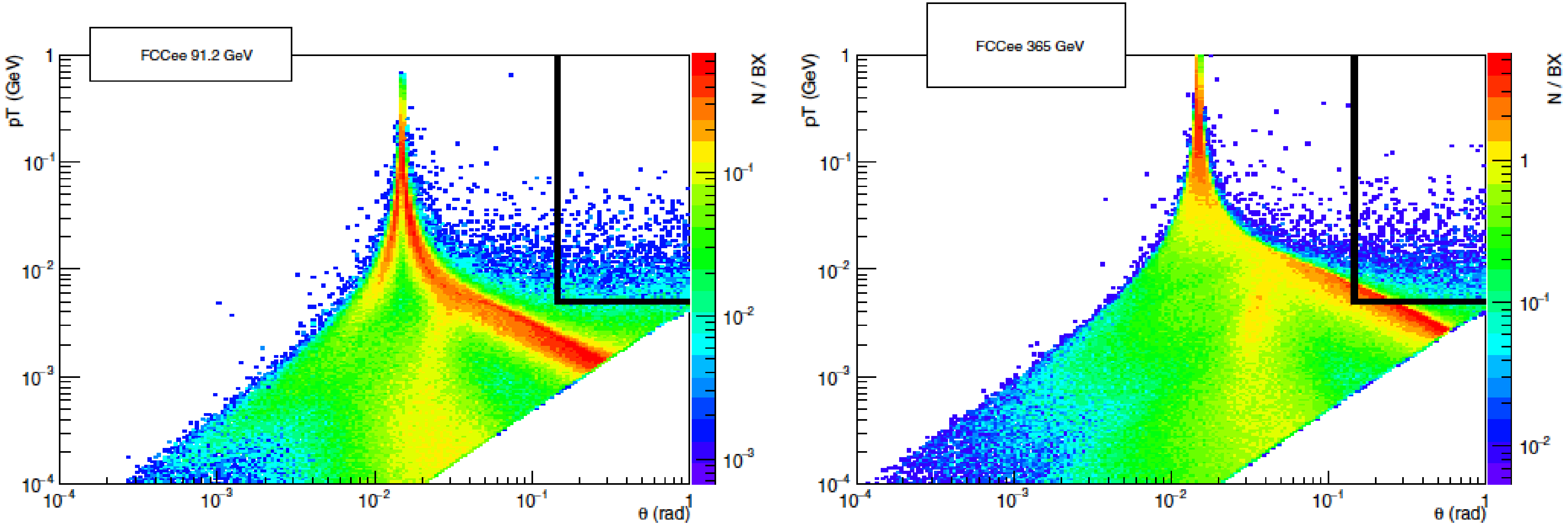


Fig. 7.2. Rates of $e^{\pm}$ from IPC in the (p_T, θ) plane, in the detector frame, for $\sqrt{s} = 91.2\,\text{GeV}$ (left) and 365 GeV (right). The black line in the upper-right corner delineates the CLD vertex detector acceptance within a field of 2 T.

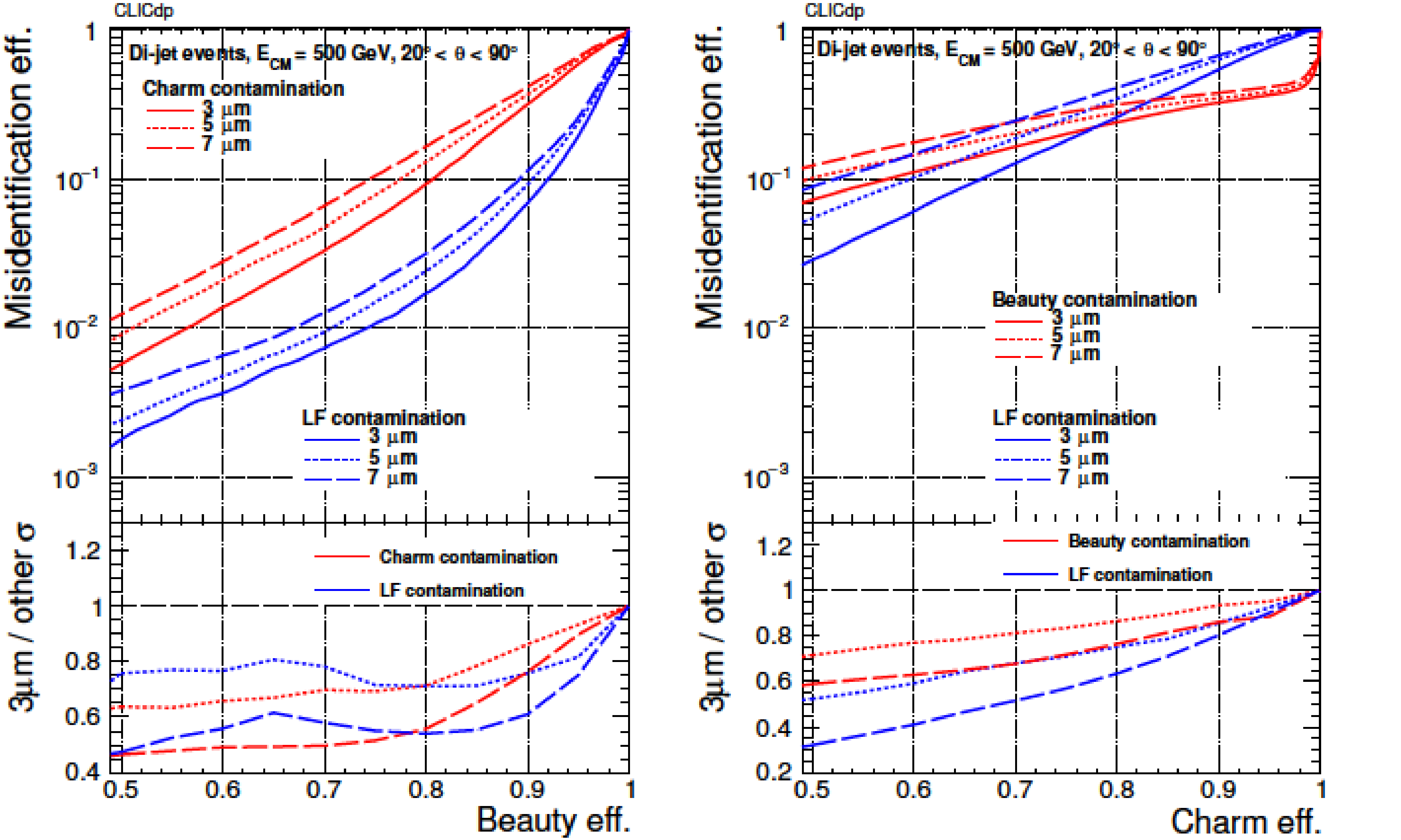
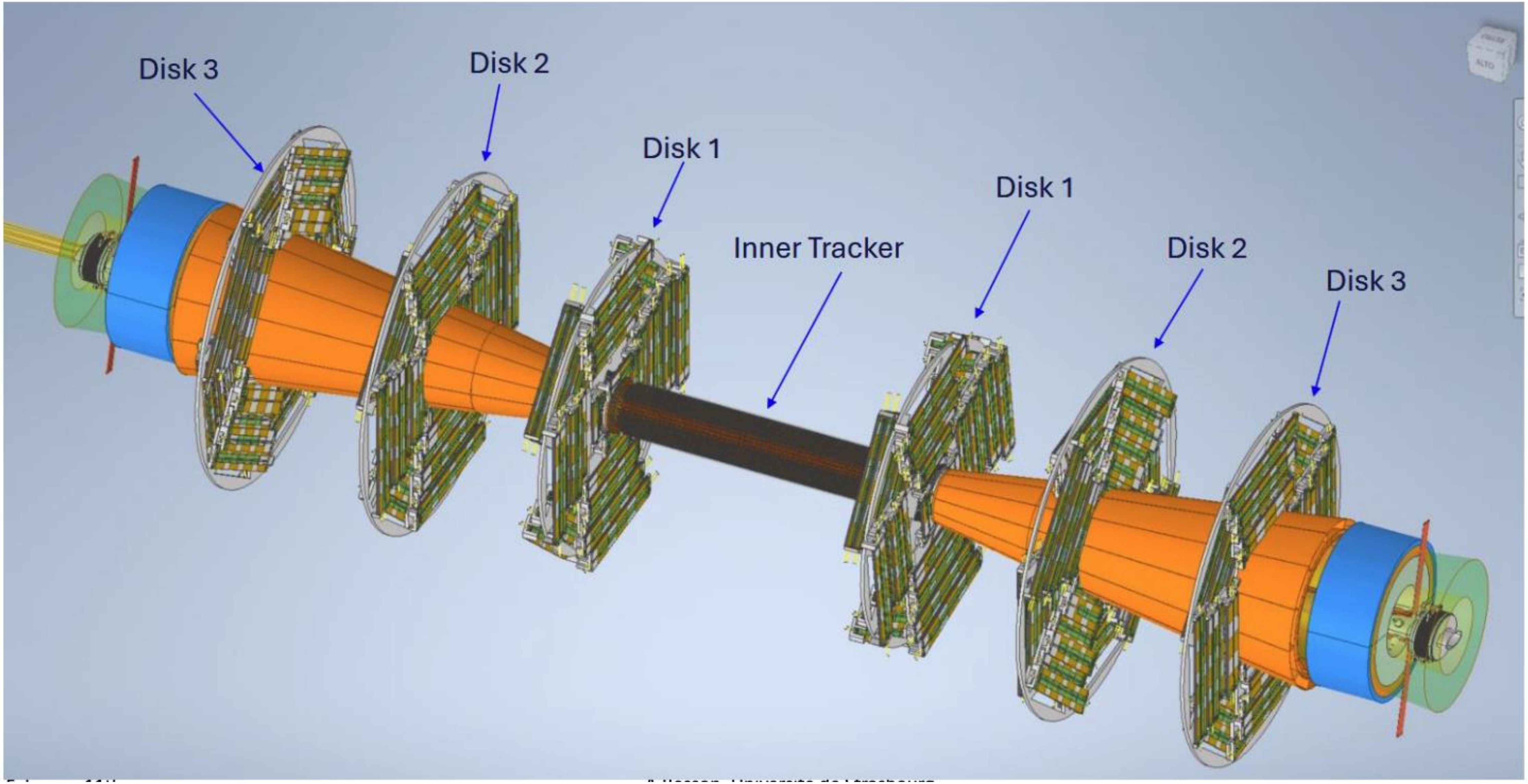


Figure 62: Global performance of beauty tagging (left) and charm tagging (right) for jets in di-jet events at $\sqrt{s} = 500\,\mathrm{GeV}$ with a mixture of polar angles between 20° and 90°. A comparison of performance obtained with different single point resolutions in the vertex detector is presented. On the y-axis, the misidentification probability and the ratio of misidentification probabilities with respect to the nominal (3 μm) single point resolution are given.


Disk 3
Disk 2
Disk 1
Inner Tracker
Disk 1
Disk 2
Disk 3

Central chamber

F.Fransesini link

The central has the following characteristics:

- **AlBeMet** 162 as main material
- **Three layers** from 0-90 mm from IP
  - 0.35 mm of AlBeMet162
  - 1 mm gap for Paraffin
  - 0.35 mm of AlBeMet162